Chapter 1

Introduction
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INTRODUCTION

The immense potential of fermentation lies in food processing and enzyme production from agro-waste that has led to major research initiatives in this field. This acts as motivation, leading the researchers to focus on its various aspects and contribute scientifically through basic as well as applied research work. Chapter 1 summarizes the fermentation process and various techniques involved in it.

1.1 Fermentation

Fermentation is a natural process which utilizes various micro-organisms to transmit mixtures of solid – liquid substrate into various valuable products. In most of the fermentation process, it requires a single species of micro-organisms to effect the desired chemical change. In major of fermentation process are classified as either (i) solid state or (ii) submerged culture. The basic difference between solid state fermentation (SSF) and submerged fermentation (SmF) is that free flowing water is present in SmF while it is absent or very minor in SSF. The role of the water content in the substrate has been widely studied and reviewed by many researchers \(^{[1,2,3]}\). The performance of SSF process depends on interface between the three key components of the system (i) bioreactor (ii) substrate and (iii) micro-organism \(^{[5,6]}\). Relative studies between SSF and SmF claim higher yields and few other advantages for products made by SSF. Since SSF has found to be a good alternative in various applications\(^{[4]}\), this research is focused on SSF, specifically on PBSSF, since it is less energy intensive with less capital investment. The pros and cons of the SSF process have been deliberated further.
1.2 SSF: A unique fermentation process

SSF is defined as a fermentation process in which micro-organisms grow on solid materials in the absence of free liquid \[^9\]. SSF is mostly used for food processing and production of enzymes using filamentous microorganism like fungi. In SSF technique, microorganisms are grown on and inside the humidified solid substrate. Trinci indirectly indicated that many of the filamentous fungi basically live and grow on solid substrate\[^7\]. Overall efficiency of the SSF basically depends on three ‘E’ factors \(i.e\). Energy, Economy and Environment \[^8\]. In SSF, substrate itself is the source of energy and requires no medium for growth of micro-organism. These solids are polymeric in nature made up of carbohydrate and or proteinaceous in nature having no tendency to break or stick with each other. SSF is heterogeneous in nature due to the presence of three phase’s \(i.e\). continuous air phase, which flows continuously through solid phase substrate with biomass, and liquid phase as water or moisture present in the substrate. SSF technology has been conventionally more applicable for filamentous fungi, which grow on the surface of the solid particles. SSF is a well adapted and cost effective process for the production of bio-products at a large spectrum and has been used widely in Asian and African countries \[^10\]. The SmF method requires more cooling water and electricity than the SSF process, which results in higher costs of utilities for the SmF method. In SSF downstream processing is easy and cost effective than SmF. SSF technology did not get wide acceptance in European countries, however owing to the benefits offered by SSF it is getting acceptance \[^11\]. Invariably use of SSF leads to minimization of the various problems related to soil pollution, the potential application in bioremediation and coming up as alternative for animal feeding lead to acceptance in European continent. SSF is a key process and widely used for producing cellulase enzyme with a wide range of natural
substrate. SSF is very complex process where the fungal hyphae forms a mat on the substrate surface and also penetrates through the substrate. SSF needs close process parameters monitoring and controlling which is very difficult practically. In major cases filamentous fungi is used in SSF while only in a few cases bacteria and yeasts can be used [12]. Various bacteria, yeasts and fungi can secrete cellulases. Structurally fungal cellulases are simpler as compared to bacterial cellulase systems, cellulosomes [13,62-64]. Growth of filamentous fungi in SSF is an aerobic process. Previously, SSF process was famous for “low volume - high cost” products due to its critical technical problems associated with heat and mass transfer for large capacity. But due to advancement in SSF technology, this process is inclining towards “high volume - high cost” products. Further, classification of SSFr needs to be understood to narrow down on a specific SSFr for a specific applications which is discussed in the below subsection.

1.3 Types of solid state fermenter:

The SSF bioreactors are broadly classified into diverse types by various researchers [10-11,61,73,76]. Majority of the researchers divided the SSFr broadly into following two types, (i) small scale and (ii) large scale fermenter. According to the operations, the SSFr can be divided into batch mode or continuous mode fermenter. Packed bed and tray fermenter are used for batch SSF processes. The tunnel, paddles and rotating drum fermenter are used for continuous or batch SSF processes. Based on design and construction, the SSFr divided mainly into four types [10].

(i) Tray type fermenter

(ii) Fluidized bed type fermenter
(iii) Horizontal drum type fermenter and

(iv) Packed bed type fermenter

Generally, for large scale production, SSFr employs either tray type or drum type fermenter. Even packed bed column can be used for large capacity; if operated in the intermittently mixed mode. A leading enzyme manufacturer in India, ‘BIOCON’ uses try type fermenter for large capacity production of immuno suppressants \(^{61,77,78}\). Each fermenter having their own advantages and disadvantages hence the application and ease of operations decide the selection of fermenter. Based on mixing and aeration Mitchell\(^{79}\) divided these SSFr into four group (Table 1.1).

Table 1.1 SSFr groups based on mixing and aeration\(^{79}\)

<table>
<thead>
<tr>
<th>Group</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group-I</td>
<td>Where bed is static or mixed only very infrequently and air is circulated around the bed.</td>
<td>Tray column</td>
</tr>
<tr>
<td>Group-II</td>
<td>Where bed is static or mixed only very infrequently and air is passed forcefully through the bed.</td>
<td>Packed bed fermenter</td>
</tr>
<tr>
<td>Group-III</td>
<td>Where bed is continuously mixed and air is circulated around the bed.</td>
<td>Rotating drum fermenter</td>
</tr>
<tr>
<td>Group IV</td>
<td>Where bed is agitated and air is passed forcefully through the bed.</td>
<td>Gas-solid fluidized bed</td>
</tr>
</tbody>
</table>

These groups are discussed in detail below
1.3.1 Group - I

A variety of SSFr have been designed and constructed in many small, pilot and large scale applications. Koji fermenter is widely practiced in Japan. Koji is the simplest and without forced aeration reactor which is a typical example of SSFr. Traditionally, Koji fermentation is performed in wooden and bamboo trays these materials which are now replaced by stainless steel chamber and trays. This type of SSFr is also known as tray fermenter where trays are arranged one above the other with appropriate gap between them. Thickness of the substrate bed within trays is between 5 to 15 cm deep. The bottom and sides of the trays are perforated for aeration. Humidified air is circulated for heat transfer within the chamber to maintain uniform temperature. However, loading and unloading is labor intensive and require large operating area. Koji comprises soybean or other grains on which mould is grown, which is traditionally used in oriental food preparation over the thousands of years [10,61,80,81].

1.3.2 Group-II

Packed bed type fermenter comprises substrate kept in a natural way without any kind of artificial mass transfer and facilities like agitation or mixing where the microorganisms do not tolerate mixing. Packed bed is usually composed of a cylindrical or rectangular column, oriented vertically, with the solid substrate retained on a perforated plate. This column needs to be cooled by aeration in majority to avoid overheating. Air is blown up through the perforated plate. Detail literature of this column has been discussed in Chapter 2.
1.3.3 Group-III

Rotating drum fermenter mixes the substrate continuously or intermittently. If mixing is done by the rotation of drum hence called as rotating drum fermenter. In this mode, cylindrical drum is moving along the central axis. Typically with low speed of 1-15 rpm has been recommended. If a rotational rate is less than 10% of the critical speed then it may be essential to include baffles within the drum\cite{79}. Intermittent rotation is potentially less destructive to fungal mycelium than the continuous rotation. Efficiency of rotating and stirred drum fermentor depends strongly on the water evaporation rate and the heat transfer between the solid bed and head space. In stirred drum fermenter, straight agitator and curved agitator performance on comparison shows that curved agitator gives better mixing in both radial and axial direction. \cite{11,82-84}.

1.3.4 Group-IV

Gas solid fluidized bed fermenter is having perforated plate through which gas is passed forcefully in upward direction so that substrate gets fluidized. Substrate used in this bed essentially needs to be non sticky, having uniform size without agglomeration. In such type of fermenter, controlling the bed temperature is comparatively easy since, the gas flow rate is maintained high in fluidized the substrate which makes heat transfer effective through convective cooling. This type of fermentor needs to have enough height to allow bed expansion. The upper part of the fermenter is needed to be wider than the bottom part and such shape of reactor helps to separate substrate particles from each other \cite{79,85}. It can be concluded from the above discussion that choice of SSFr and quantum of process is dependent upon the substrate, microorganism characteristics etc., therefore lot of changes were warranted and researchers tried some innovations in SSF which is discussed below.
1.4 Innovation in SSFr:

In the last few years, some attractive and curious novel designs for SSFr have been proposed. Durand and Chereau\cite{86} developed a pilot fermenter for protein enrichment of sugar beet pulp. His design of fermenter is having rectangular shape with varying capacities. The fermenter was not insulated and did not allow to maintain sterility. Three vertical screws were arranged inside the fermentor so that the substrate could mix and move in the vessel. It consisted of air conditioning system and continuous process parameter monitoring and controlling system. Vitureses et al.,\cite{87} developed a SmF-SSF combine fermenter in a single vessel as shown in Fig.1.1. This fermenter has the unusual features of SSF and SmF in combination conferring benefits.

![Fig. 1.1 SmF-SSF combine fermenter](image)
Zymotis \cite{34} developed plate type solid state fermenter as shown in Fig. 1.2 called as “Non-mixed reactor-Zymotis”. Schematic representation of Zymotis is very similar to that of plate type heat exchanger. It consists of a vertical heat transfer plates or columns through which cold water is circulated. Between each column, substrate is loaded and air is forcefully inserted though the bottom \cite{11}. However, loading and unloading is difficult in this reactor, since the space between two plates is very less.

Fig.1.2 Non-mixed reactor- Zymotis

Mitchell and Sangsurasak \cite{79} suggested three possible concepts of continuous SSF, (i) continuous stirred tank bioreactor (CSTB), (ii) continuous rotating drum bioreactor (CRDB), and (iii) continuous tubular flow bioreactor (CTFB). Jeffries \cite{88} used number of conveyor belts in the fermentation run while Tao \textit{et al.}, \cite{89} developed ‘Periodic pressure solid state fermenter’ (PPSSF) which ensures high oxygen availability inside solid bed and also gives efficient heat removal from bed. PPSSF is
suitable for closed static fermentation to produce value added product. Rivela and Couto\cite{90} worked on a new fermenter called as Immersion Fermenter. This fermenter consisted of a jacketed cylindrical glass vessel with round bottom. Inside the vessel many wired mesh baskets are placed which are colonized by the fungus for fermentation.

Tunnel fermenter is an alteration of the static – bed fermenter. In tunnel fermenter the bed of the solid is comparatively very long, but height is not more than 0.5 m. Perez-Correa and Agosin\cite{91} developed, a 50 kg capacity Rotating Basket Fermenter where stationary blades were provided for mixing and nozzles were provided for water sprinkling. Air can be passed from bed of substrate through perforated plate, provided at the bottom of reactor. In this manner, various researchers applied several other types of design in SSFr to fulfill their specific task. In the last few years, researchers focused on packed bed column, as this type of fermenter can provide improved process economics and easier material handling \cite{92}. The importance of packed bed column in SSF is again due to their simple design and construction. These innovations in fermenter are widely accepted and hence applied for the production of enzymes on commercial scale. The enzyme production by SSF is discussed in the below subsection.

1.5 Enzyme production by SSF

Enzymes are among the vital products produced mostly by SSF. Generally, hydrolytic enzymes (e.g. cellulases, xylanases, pectinases etc.)\cite{93} are produced by fungal cultures which are filamentous in nature and hence SSF is the method of choice for its production. In current studies, SSF has been implied for the production of cellulases by a locally isolated micro-organism. Cellulose is one of the most abundant and
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renewable carbohydrate biopolymer on the earth. Cellulose is used as an energy
source by various bacteria, yeasts and fungi. Proper biotechnological utilization of
these materials in the environment has potential to eliminate pollution and convert
cellulosic biomass into useful by-product. Cellulases produced by microbes are a
group of hydrolytic enzymes capable of degrading cellulose to the smaller
monosaccharide glucose units [14]. It has been reported that SSF is an attractive
process to produce cellulase economically due to its lower capital investment and
operating cost [15]. For the maximum yield of enzyme, it is essential to provide
optimum parameters initially for the growth of organism followed by optimum
parameters for products formation. The optimum parameters include physico-
chemical parameters like substrate, inoculums concentration, humidity, pH,
temperature etc. In case of fungi, temperature is a very important parameter. Hence,
fungal growth in SSF is significantly affected by the temperature of the reactor. The
substrates used for SSF have low thermal conductivity which provides resistance to
heat transfer. Due to this metabolic heat accumulate in the bed which increases
temperature of the bed which may not be favorable for fungi. Therefore the key issue
in SSF is heat removal, and has become a focal point in research on SSF. Even
reducing the substrate bed height can solve the heat transfer problems, but it is
possible only in small scale SSF [16] while it remains unanswered in case of large scale
SSF.

1.5.1 Cellulase

Cellulase is an enzyme having potential applications in various industries.
Lignocellulosic agro-waste is the substrate choice for cellulase production which
decreases the cost of cellulase production. Lignocellulosic materials are cheaper and
abundantly available but needs pretreatment for its effective utilization. These
enzymes produced by a large number of microorganisms including both fungi and bacteria. These microorganisms can be aerobic, anaerobic and thermophilic. SSF is mostly preferred for cellulase production due to its lower capital investment and operating cost. Cellulases have been commercially available from long time, however, the challenge of increasing its yield has been a target for both academic as well as industrial research\cite{17,18}. Cellulase is a complex of enzymes having mainly endo and exoexo-1,4 glucanase and β–glucosidase activities. Cellulases are used for the production of glucose, ethanol, extraction of fruit and vegetable juices, deinking of the recycled paper pulp and for improving cattle feed quality\cite{10}. Tenerdy (1996)\cite{19} compared cellulase production in SmF and SSF system and interestingly found that SSF was economical technology for the production of cellulase. Conversely, total enzyme production was 12 times higher in SSF than in SmF under similar experimental conditions\cite{4}. The production of cellulase by SSF technology has been studied by many researchers using different microorganisms, substrates and media. Agricultural residues available abundant in quantity such as sorghum, wheat, rice straw, bagasse, banana wastes, coconut coir pitch, coffee pulp, soybean hulls etc. can be used for cellulase production. High content cellulosic composition is good for fungal growth and cellulase production. Generally, these cellulosic materials need to be pretreated for the efficient synthesis and production of enzyme cellulase. Fungal strains that produce cellulases mainly are members of genera *Aspergillus*, *Trichoderma*, *Penicillium*, *Fusarium generas*, *Clostridium*, *Cellulomanas* and *Thermomonospora* \cite{20,46-49}. Fungal strains of *Aspergillus* (one of the oldest named genera of fungi, *Aspergillus* received its name from Micheli in 1729) are high in β–glucosidase activities where as the funal strains of *Trichoderma* are poor in β–glucosidase activities. *Trichoderma* shows high activity of endo and exo-glucanase
activity. In a few cases a combination of two fungi in SSF was found to enhance the enzyme production. Brijwanit et al. (2010)[20] used combination of T. reesi and A.Oryzae in 1:1 ratio and found that the production of β – glucosidase level in SSF increased when soybean hulls when used with wheat bran. Combination of Aspergillus ellipticus and Aspergillus fumigates resulted in improved hydrolytic and β – glucosidase activity [59,60]. Cellulase production is affected by various factors like nature of solid substrate employed, particle size, water activity, temperature and pH, etc. Table 1.2 indicates the bibliographic details of cellulases production by various micro-organisms.

Table 1.2 Cellulases produced by various micro-organisms.

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Substrate</th>
<th>Micro-organism</th>
<th>Enzyme</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alfalfa</td>
<td>Gliocladium spp.</td>
<td>Cellulase</td>
<td>[22]</td>
</tr>
<tr>
<td>2</td>
<td>Cassava bagasse</td>
<td>Tricoderma reesei</td>
<td>Cellulase</td>
<td>[36]</td>
</tr>
<tr>
<td>3</td>
<td>Chaff and Wheat bran mixture (Ratio of 7:3 (W/W))</td>
<td>Trichoderma viride</td>
<td>Cellulase</td>
<td>[33]</td>
</tr>
<tr>
<td>4</td>
<td>Forage silage</td>
<td>Streptomyces achromogenes</td>
<td>Cellulase</td>
<td>[23]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hemicellulase</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Jowar straw (JS)</td>
<td>Aspergillus oryzae</td>
<td>Cellulase</td>
<td>[32]</td>
</tr>
<tr>
<td>6</td>
<td>Rice straw (RS)</td>
<td>Trichoderma reesei</td>
<td>Cellulase</td>
<td>[21]</td>
</tr>
<tr>
<td>7</td>
<td>Sugarcane bagasses</td>
<td>Trichoderma reesei, Phanerochaete Chrysoporium, Coriolus versicolor, Streptomyces viridosporus</td>
<td>Cellulase Ligninase</td>
<td>[29,30]</td>
</tr>
</tbody>
</table>

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In various agricultural residues mixed cultivation results in a better cellulase production with efficient lignocelluloses degradation \cite{39,57}. Various combinations of cellulases, hemicellulases and pectinases were developed for better growth of crops and controlling their diseases \cite{17}. Microbial cellulases have become a crucial biocatalyst due to their complex nature and extensive industrial applications. Different combination of cellulases, hemicellulases and pectinases have potential applications in agriculture to enhance growth of crops and control of crop diseases \cite{37,38}. The economy of cellulase production could be enhanced by the use of cheaper cellulosic natural substrate \cite{36,46,53-56}. To produce these enzymes, the substrates are the key ingredients, and are discussed in the below section.
1.6 Substrates for SSF

India is a large agricultural country. Variety of crops is produced in large quantities across India e.g. wheat, rice, cotton, soyabean, jowar and tur etc. Crop waste referred as agrowaste or straw is having economical value due to its nutritional potential and can be used as substrate in SSF. Presently in most of the cases, these straw materials are used either as animal feed or most of the material for burning as fuel or an easy way of disposal resulting environmental pollution. After processing these materials in SSF, its nutritional value can be increased for use as animal feed while enzyme can be separated a main product. However, it depends on the type of fungus used for fermentation. This technique has a potential to increase the income of rural people. In SSF processes, substrate is a source of energy for microorganisms. In nature, lignocellulose is synthesized in tremendous amount in the form of grass, wood, agricultural residues and forestry wastes etc. Solid substrate employed in SSF processes are insoluble in water and act as a source of carbon, nitrogen and minerals required for growth. Filamentous fungi penetrate deeply into solid substrate particles to avail the required nutrients whereas, bacteria and yeast grow only on the surface of the solid substrate particles [40].

Due to inadequate mixing characteristics of heterogeneous media of SSF, it is very difficult to control parameters like pH and temperature of the SSF system [94]. Therefore, to address these challenges research work is essential to understand this process critically. The ratio of C:N of the substrate carries high importance in view of selection of substrate which generally needs to be 16.0. However, it is difficult to get so, hence it needs to select substrate having better C:N ratio. Hence, various substrate locally available having comparatively better C:N ratio is very important in view of making the SSF process economically viable. Among various agrowaste available in
India especially in Maharashtra state, wheat, jowar and rice straw are abundantly available. Jowar crop is very much habitual to unfavorable environmental conditions, like drought and salinity hence; in the drought prone area it is always available. Generally, a single type of substrate or mixture of two or more substrates can be used in SSF. Mostly, all these solid wastes show the presence of nutrients and moisture hence suitable for micro-organisms growth. Many of cost effective substrates are generally insoluble in water and water is absorbed by it. This absorbed water supports the biochemical reactions of life and substrate is used by microorganisms for growth. The selection of a substrate for SSF process depends upon several factors, however; their screening mainly depends on the C:N ratio as discussed, cost and its availability. Substrate can be divided into three groups, substrate with soluble sugar, starchy substrates and cellulosic substrate. Table 1.3 gives bibliographic revision of various substrates used in SSF process.

Table 1.3 Various substrates used in SSF \[^{[9,31,60,72-75,95]}\].

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Substrate</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i)</td>
<td>Substrate With soluble sugar</td>
<td>Banana waste, apple pomace, Sweet lime waste, grape pomace, sweet sorghum waste, sugar beet waste, Kiwi fruit peel, pineapple waste, mixed fruit waste, Orange peels and hemp with soluble sugars etc.</td>
</tr>
<tr>
<td>(ii)</td>
<td>Starchy substrate</td>
<td>Rice, cassava, buckwheat seeds, corn meal, sweet potato residue, banana meal, jack fruit seed waste etc.</td>
</tr>
<tr>
<td>(iii)</td>
<td>Cellulosic substrate</td>
<td>WS, JS, corn rice stover, rice bran, wheat bran, sugar beet pulp, TS, Soyabean straw, wood etc.</td>
</tr>
</tbody>
</table>
The mixtures of many different, two substrates have been reported such as mixtures of soybean hulls with wheat at the ratio of (4:1 W/W) \[20\], groundnut oil cake with wheat bran (1:1 W/W)\[50\], olive oil cake with sugarcane bagasse (1:1 W/W)\[51\], coconut oil cake with sesame oil cake (1:1 W/W)\[52\] etc. The water activity plays a very crucial role in SSF. Water activity (\(a_w\)) of substrate is very crucial parameter in SSF. The \(a_w\) gives the amount of unbounded water available in the surroundings of the microorganism. The water activity (\(a_w\)) is defined as the ratio of vapor pressure of an aqueous solution to that of pure water at the same temperature \[58\]. It is closely related but not equal to, the water content of the bed. Generally in SSF low water activity (\(a_w\)) is preferred. Since, fungi can grow in SSF culture at low \(a_w\) and low \(a_w\) helps avoiding bacterial growth because bacteria needs high \(a_w\) for their growth\[65-67\]. Fermenter size reduces and a more concentrated product is produced due to low \(a_w\) requirement in SSF\[68\]. But, the substrate should have adequate moisture to support growth and metabolic activities of the organisms. Derived water activity value depends on the types of microorganism employed and substrate engaged in the process. Fungi are selected as micro-organism for SSF because their hyphae can grow on particle surfaces and penetrate into the inter-particle spaces efficiently and thereby colonize solid substrates \[41\]. Lignocellulose material mainly consists of three type of polymers (i) cellulose, (ii) hemicelluloses, and (iii) lignin. Studies with inert substrates like polyurethane foam wetted with dissolved nutrients have been also reported in literature \[42\]. In most of the SSF process, substrate needs preparation and pre-treatment before loading it into fermenter, involving size reduction by grinding, screening substrate particle sizes, cooking or vapor treatment, supplementation with nutrients and pH settling. After treatment substrate should have high surface area to volume ratio and absorb water amounting one or several times to its dry weight. The
C:N ratio plays very crucial role for selecting proper substrate for SSF and selection of substrate also depends on the enzyme of interest for example, for the production of cellulase, cellulosic rich substrates can be selected like RS, JS and WS. In the same way, for the synthesis of pectinases substrate like apple, avocado pulp (generally fruit pulp) can be selected \[43\]. Poor thermal conductivity of substrate presents a great challenge to design SSF. The particle shapes of substrate affect the flow pattern in the bed, which also affects O\(_2\) distribution inside the bed. Fig. 1.3 shows the irregular shapes and size of substrate after screening through a mesh size of 85 and Fig.1.4 shows the arrangement of wetted solid particles with a continuous gas phase in SSF systems. Irregular shape of the substrate particles are bound to affect the packing pattern inside the packed column. However, it is very difficult practically to find the effect of these irregular shapes on various parameters of the SSF process, but it can certainly be said that it has inherent ability to affect the fungal growth and productivity of SSF.

Fig. 1.3: Size and shape of substrate after screening through a mesh size of 85.
Fig. 1.4 The flow of continuous gas phase in SSF through solid substrate.

Fig.1.4 indicates spaces between the substrate, which contain a continuous gas phase and very less visible water. The droplet of water may be present between the solid particles and a thin film of water while biomass is present on the surface of solid particles.

All the above discussion on SSF has shown its wide applicability and therefore why the research is focused on SSF is discussed in below subsection.

1.7 SSF for research: A critical approach

SSF has gained importance in recent years owing to the advancement in the instrumentation and knowledge generated. The following are some of the advantages of SSF\cite{44,45}. 
Advantages:

(i) Less water requirement

(ii) No foam formation inside the reactor

(iii) Low energy requirement

(iv) Downstream processing cost is very low and process is environment friendly

(v) Simpler technique

(vi) Better-quality and productivity of product

(vii) Low Substrate cost with abundant availability

(viii) Reduces the problems associated with solid wastes disposal.

(ix) Less chances of bacterial contamination

(x) Liquid waste is very less.

Thus, SSF gives numerous advantages for the production of bulk chemicals and enzymes \(^{[69-71]}\). SSF technology is still in research stage and waiting for advancements in heat and mass transfer, biomass separation and process control \(etc\). This technology is also showing certain technical disadvantages \(^{[8-10,44]}\) as listed.

Disadvantages:

(i) Uneven temperature gradients

(ii) Difficulties in handling large volume of solids

(iii) Difficulties in scale up

(iv) Difficulties in proper distribution of \(O_2\) to the biomass

(v) Difficulties in biomass determination

(vi) Longer cultivation duration

(vii) Channeling difficulties
(viii) Tedious and expensive substrate pretreatment methods

(ix) Labor intensive process and hard to control process parameters.

In spite of the fact that SSF poses enormous difficulties and critical process control, low cost is the driving force behind its acceptance over the SmF and hence its popularity is increasing day by day. Eventhough, there are many difficulties associated with SSF. It has proved to be a cost effective technology for cellulase production. Therefore, an important research task using local micro-organism on JS substrate in SSF was undertaken where specific experiments related with process along with modeling and parameter comparison of modeling were carried out. Keeping SSF as a base further literature review on packed column was carried out in Chapter 2. All of five objectives set for this research were as follows.

1.8 Objectives of the research:

The following are objectives set for carrying out the research on SSF

a. To find suitable local substrate for SSF

b. To find potent cellulase producer from local area

c. To find optimum parameters for lab scale SSF

d. To study axial temperature gradients formed inside the packed bed

e. The rigorous mathematical modeling and simulation to validate experimental data to find out various parameters involved there in.
References:


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