Introduction:

Industrial microbiology may be defined as the study of the large-scale and profitmotivated production of microorganisms or their products for direct use, or as inputs in the manufacture of other goods. Thus yeasts may be produced for direct consumption as food for humans or as animal feed, or for use in bread-making; their product, ethanol, may also be consumed in the form of alcoholic beverages, or used in the manufacture of perfumes, pharmaceuticals, etc. Industrial microbiology is clearly a branch of biotechnology and includes the traditional and nucleic acid aspects.

CHARACTERISTICS OF INDUSTRIAL MICROBIOLOGY

The discipline of microbiology is often divided into sub-disciplines such as medical microbiology, environmental microbiology, food microbiology and industrial microbiology. The boundaries between these sub-divisions are often blurred and are made only for convenience.

THE USE OF THE WORD 'FERMENTATION' IN INDUSTRIAL MICROBIOLOGY

The word fermentation comes from the Latin verb *fevere*, which means to boil. It
originated from the fact that early at the start of wine fermentation gas bubbles are
released continuously to the surface giving the impression of boiling. It has three different meanings which might be confusing.

The first meaning relates to microbial physiology. In strict physiological terms,
fermentation is defined in microbiology as the type of metabolism of a carbon source in which energy is generated by substrate level phosphorylation and in which organic molecules function as the final electron acceptor (or as acceptors of the reducing equivalents) generated during the break-down of carbon-containing compounds or catabolism.
As is well-known, when the final acceptor is an inorganic compound the process is called respiration. Respiration is referred to as aerobic if the final acceptor is
oxygen and anaerobic when it is some other inorganic compound outside oxygen e.g sulphate or nitrate.

The second usage of the word is in industrial microbiology, where the term 'fermentation' is any process in which micro-organisms are grown on a

large scale, even if the final electron acceptor is not an organic compound (i.e. even if the growth is carried out under aerobic conditions). Thus, the production of penicillin, and the growth of yeast cells which are both highly aerobic, and the production of ethanol or alcoholic beverages which are fermentations in the physiological sense, are all referred to as fermentations.

The third usage concerns food. A fermented food is one, the processing of which microorganisms play a major part. Microorganisms determine the nature of the food through producing the flavor components as well deciding the general character of the food, but microorganisms form only a small portion of the finished product by weight. Foods such as cheese, bread, and yoghurt are fermented foods.

Plants and animals as well as their cell cultures are also used in biotechnology, and
will be discussed in the appropriate sections below.
Microorganisms have the following advantages over plants or animals as inputs in biotechnology:
i. Microorganisms grow rapidly in comparison with plants and animals. The generation time (the time for an organism to mature and reproduce) is about
12 years in man, about 24 months in cattle, 18 months in pigs, 6 months in chicken, but only 15 minutes in the bacterium, *E coli.* The consequence is that
biotechnological products which can be obtained from microorganisms in a matter
of days may take many months in animals or plants.

ii. The space requirement for growth microorganisms is small. A 100,000 litre
fermentor can be housed in about 100 square yards of space, whereas the plants or
animals needed to generate the equivalent of products in the 100,000 fermentor
would require many acres of land.

iii. Microorganisms are not subject to the problems of the vicissitudes of weather
which may affect agricultural production especially among plants.

iv. Microorganisms are not affected by diseases of plants and animals, although they do have their peculiar scourges in the form phages and contaminants, but there are procedure to contain them.

CHARACTERISTICS IMPORTANT IN MICROBES USED IN INDUSTRIAL MICROBIOLOGY AND BIOTECHNOLGY

Microorganisms which are used for industrial production must meet certain requirements including those to be discussed below. It is important that these
characteristics be borne in mind when considering the candidacy of any microorganism as an input in an industrial process.

i. The organism must be able to grow in a simple medium and should preferably not require growth factors (i.e. pre-formed vitamins, nucleotides, and acids) It is obvious that extraneous additional growth factors may increase the cost of the
fermentation and hence that of the finished product.

ii. The organism should be able to grow vigorously and rapidly in the medium in use.

iii. Not only should the organism grow rapidly, but it should also produce the desired materials, whether they be cells or metabolic products, in as short a time as
possible.

iv. Its end products should not include toxic and other undesirable materials,
especially if these end products are for internal consumption.

v. The organism should have a reasonable genetic, and hence physiological stability.
An organism which mutates easily is an expensive risk. It could produce undesired products if a mutation occurred unobserved. The result could be reduced yield of the expected material, production of an entirely different product
or indeed a toxic material.

vi. The organism should lend itself to a suitable method of product harvest at the end of the fermentation. If for example a yeast and a bacterium were equally suitable for manufacturing a certain product, it would be better to use the yeast if the most appropriate recovery method was centrifugation.

vii. Wherever possible, organisms which have physiological requirements which
protect them against competition from contaminants should be used. An organism
with optimum productivity at high temperatures, low pH values or which is able to
elaborate agents inhibitory to competitors has a decided advantage over others.
Thus a thermophilic efficient producer would be preferred to a mesophilic one.

viii. The organism should be reasonably resistant to predators such as bacteriophages.

ix. Where practicable the organism should not be too highly demanding of oxygen as aeration (through greater power demand for agitation of the fermentor impellers,
forced air injection etc) contributes about 20% of the cost of the finished product.

x. Lastly, the organism should be fairly easily amenable to genetic manipulation to
enable the establishment of strains with more acceptable properties.

Examples of industrial fermentation products and their producer microorganisms

Table 4.1 Examples of industrial fermentation products and their producer microorganisms

	Bacteria	Yeasts and filamentous fungi
Traditional products		
Bread, beer, wine and spirits		Mainly *Saccharomyces cerevisiae*
Cheeses, other dairy products	Lactic acid bacteria	
Ripening of blue and Camembert-type cheeses		*Penicillium* species
Fermented meats and vegetables	Mostly lactic acid bacteria	
Enzymes		
Carbohydrases		
α-amylase	*Bacillus subtilis*	
β-amylase		*Aspergillus niger*
amyloglucosidase		*Aspergillus niger*
glucose isomerase	*Streptomyces olivaceus*	
invertase		*Kluyveromyces* species
lactase (β-galactosidase)		*Kluyveromyces lactis*
Cellulases		*Trichoderma viride*
Lipases		*Candida cylindraceae*
Pectinases		*Aspergillus wentii*
Proteases		
subtilisin (alkaline)	*Bacillus licheniformis*	
Antibiotics		
Aminoglycosides		
streptomycin	*Streptomyces griseus*	
β-Lactams		
penicillins		*Penicillium chrysogenum*
cephalosporins		*Acremonium chrysogenum*
clavulanic acid	*Streptomyces clavuligerus*	
Lantibiotics		
nisin	*Lactococcus lactis*	

Hormones		
Human growth hormone	Recombinant *Escherichia coli*	Recombinant *Saccharomyces cerevisiae*
Insulin	Recombinant *Escherichia coli*	Recombinant *Saccharomyces cerevisiae*
	Salmonella typhi	
Vitamins		
B_{12} (cyanocobalamin)	*Pseudomonas denitrificans*	
β-Carotene (provitamin A)		*Blakeslea trispora*
Ascorbic acid (vitamin C)	*Acetobacter suboxydans*	
Riboflavin	Recombinant *Bacillus subtilis*	*Ashbya gossypii*
Vaccines	*Bacillus anthracis*	
	Clostridium tetani	
	Recombinant *Escherichia coli*	
	Salmonella typhi	