Hydrocarbon Degrading Bacteria-Taxonomy & Facts of Bacteria.

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Brief facts

Bacteria generally degraders in aquatic systems such as oceans, ponds and other water reservoir. They also possess diverse metabolic pathways which is not seen in fungi which allows them to utilize most *recalcitrant petroleum hydrocarbons*.

- Bacterial degradation of aromatic compounds can be divided into three steps:
    1. modification and conversion of the many different compounds into a few central aromatic intermediates (*ring-fission substrates*); this step is referred as *peripheral pathway* and involves considerable modification of the ring and/or perhaps elimination of substituent groups;
    2. oxidative ring cleavage by dioxygenases, which are responsible for the oxygenolytic ring cleavage of dihdyroxylated aromatic compounds (catechol, protocatechuate, gentisate);
    3. further degradation of the non-cyclic, non-aromatic ring-fission products to intermediates of central metabolic pathways.
- Long-chain hydrocarbons (C_{10}-C_{18}) can be used rapidly by many high G+C Gram-positive bacteria. Only a few bacteria can oxidize C_2-C_8 hydrocarbons. Degradation of *n*-alkanes requires activation of the inert substrates by molecular oxygen with help of oxygenases by

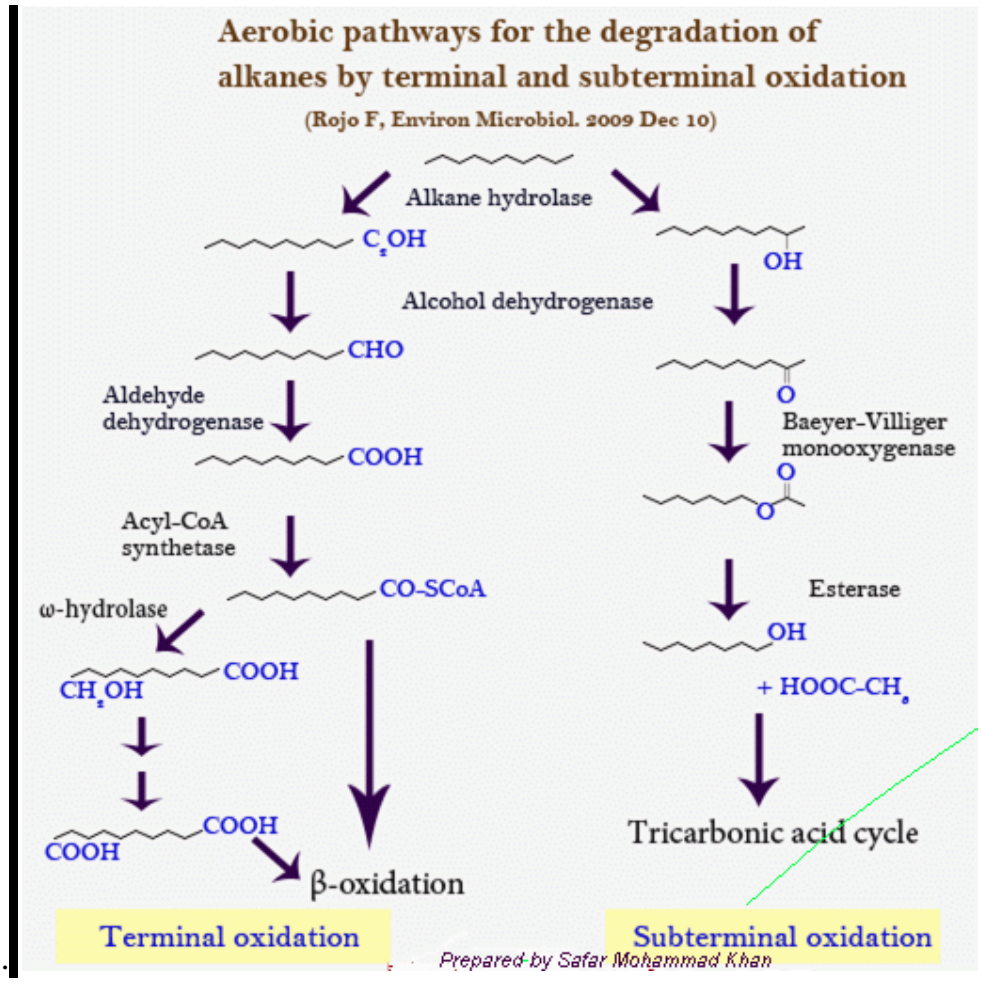
BACTERIA

Bacteria ,*singular*: **bacterium**) are a large domain of single-celled, prokaryote microorganisms. Typically a few micrometres in length, bacteria have a wide range of shapes, ranging from spheres to rods and spirals. Bacteria are ubiquitous in every habitat on Earth, growing in soil, acidic hot springs, radioactive waste,[2] water, and deep in the Earth's crust, as well as in organic matter and the live bodies of plants and animals. There are typically 40 million bacterial cells in a gram of soil and a million bacterial cells in a millilitre of fresh water; in all, there are approximately five nonillion (5×10^{30}) bacteria on Earth,[3] forming a biomass on Earth, which exceeds that of all plants and animals.[4] Bacteria are vital in recycling nutrients, with many steps in nutrient cycles depending on these organisms, such as the fixation of nitrogen from the atmosphere and putrefaction. However, most bacteria have not been characterised, and only about half of the phyla of bacteria have species that can be grown in the laboratory.[5] The study of bacteria is known as bacteriology, a branch of microbiology.

three possible ways that are associated with membranes:

1. Monooxygenase attacks at the end producing alkan-1-ol:
   $R\text{-}CH_3 + O_2 + NAD(P)H + H^+ \rightarrow R\text{-}CH_2OH \_ NAD(P)^+ + H_2$
2. Dioxygenase attack produces the hydroperoxides, which are reduced to yield also alkan-1-ol:
   $R\text{-}CH_3 + O_2 \rightarrow R\text{-}CH_2OOH + NAD(P)H + H^+ \rightarrow R\text{-}CH_2OH + NAD(P)^+ + H_2O$
3. Rarely, subterminal oxidation at C2 by monooxygenase yields secondary alcohols.

- It is important to keep in mind that many strains within one species of bacteria usually exist. Usually, only some of strains are capable of hydrocarbon degradation and some of strains can cause opportunistic infections in humans and animals.



List of bacterial genera important in oil bioremediation

Actinobacteria

- Micrococcaceae
  - Arthrobacter *Arthrobacter* spp. were shown to degrade various aromatic hydrocarbons such as phenanthrene (Ref.) and others (Ref.).
  - Micrococcus Isolated from oil-biodegrading consortia in marine environment (Ref.).

 Brevibacteriaceae

- Brevibacterium These bacteria were isolated from petroleum-degrading consortia (Ref.).

 Dermabacteraceae

- Brachybacterium *B. phenoliresistens* was isolated from an oil-contaminated coastal sand sample (Ref.).

 Dietziaceae

- Dietzia Marine hydrocarbon-utilizing bacteria (Ref.).

 Cellulomonadaceae

- Cellulomonas Sediment hydrocarbon-utilizing bacteria (Ref.).

 Intrasporangiaceae

- Janibacter Implicated in degradation of polycyclic hydrocarbons (PAHs) (Ref.).
- Terrabacter Implicated in degradation of polycyclic hydrocarbons (PAHs) in *marine sediments* (Ref.).

 Corynebacteriaceae

- Mycobacterium Some species can utilize polycyclic hydrocarbons (PAH) and other pollutants (Ref.).
- Corynebacterium Isolated from oil-degrading consortia (Ref.).

 Gordoniaceae

- Gordonia Some strains also utilize oil ingredients (Ref.).

 Nocardioidaceae

- Nocardioides Most species are free-living in *soil and water*. Some species can utilize polycyclic hydrocarbons (PAH) and other pollutants (Ref.).
- Rhodococcus Some species can utilize polycyclic hydrocarbons (PAH) and other pollutants (Ref.).

 Nocardiaceae

- Nocardia (Ref.).
- Smaragdicoccus (Ref.).
- Cyanobacteria Cyanobacteria can play important role in oil-degrading consoria by not only oxydizing oil components but also by providing microbial community with nitrogen

 Bacteroidetes/
Chlorobi group

- Flavobacteria
  - Chryseobacterium Were isolated from stable carbazole-degrading consortium with *Achromobacter* (Guo W et al, 2008) and other oil-degrading bacterial communities (Ref.).
  - Flavobacterium Some strains are capable of degrading polycyclic aromatic hydrocarbons and heterocyclics (Ref.).
  - Yeosuana A marine bacterium, *Y. aromativorans* GW1-1T, capable of degrading benzo[a]pyrene (BaP) (Ref.).

 Deinococcus-Thermus

- Thermaceae
  - Thermus Aerobic rods found in warm water (40-79 C°) such as hot springs, hot water tanks, and thermally polluted rivers; can degrade crude oil (Ref.).

 Thermotogae

- Thermotogaceae
  - Petrotoga (Ref.).

 Firmicutes

- Bacillaceae Endospore-producing; mostly saprophytes from soil, but a few are insect or animal parasites or pathogens.
  - Bacillus Common in *soil*; several species (*B. subtilis*, *B. cereus* and others) were shown to use naphthalene, pyrene and other aromatics (Ref.).

- Geobacillus Endospore-forming, thermophilic bacteria capable of utilizing long-chain alkanes (Ref.).
- Staphylococcaceae
  - Staphylococcus Some species are opportunistic pathogens of humans and animals. Pathways of utilization of phenanthrene and other aromatic compounds by these organisms was studied (Ref.).

- Proteobacteria

- Alphaproteobacteria Comprised mostly of two major phenotypes: purple non-sulfur bacteria and aerobic bacteriochlorophyll-containing bacteria.
  - Sphingomonadaceae
    - Sphingomonas Degrade a broad range of substituted aromatic compounds (Ref.).
    - Sphingobium Degrade a range aromatic compounds (Ref.).
  - Rhodobacteraceae
    - Paracoccus Hydrocarbon-utilizing bacteria (Ref.).
    - Stappia Alkaliphilic and halophilic hydrocarbon-utilizing bacteria (Ref.).
    - Roseobacter Marine hydrocarbon-utilizing bacteria (Ref.).
  - Rhodospirillaceae
    - Thalassospira A polycyclic aromatic hydrocarbon-degrading marine bacterium (Ref.).
    - Tistrella A phenanthrene-degrading marine bacterium (Ref.).
  - Brucellaceae
    - Ochrobactrum A polycyclic aromatic hydrocarbon-degrading marine bacterium (Ref.).
    - Rickettsiales
      - SAR11 cluster
        - Candidatus Pelagibacter
  - Betaproteobacteria Comprised of chemoheterotrophs and chemoautotrophs which derive nutrients from decomposition of organic material.
    - Alcaligenaceae
      - Achromobacrer Were isolated from stable carbazole-degrading consortium with *Chryseobacterium* (Guo W et al, 2008) and other oil-degrading bacterial communities (Ref.).
      - Alcaligenes Implicated in degradation polycyclic aromatic hydrocarbons (PAH) from oil and other pollutants (Ref.).
    - Comamonadaceae

        - Acidovorax Has been found in consortia utilizing heterocyclic aromatics (Ref.)
        - Polaromonas Has been shown to utilize naphthalene, benzene, toluene (Ref.)
    - Burkholderiaceae
        - Burkholderia Found in consortia of microorganisms degrading polycyclic hydrocarbons (PAH) and other environmental pollutants (Ref.).
        - Ralstonia Free-living forms are known to utilize polycyclic hydrocarbons (PAHs) (Ref.).
    - Rhodocyclaceae
        - Azoarcus Gram-negative, facultatively anaerobic bacteria including species which are often associated with grasses and which fix nitrogen as well as species which anaerobically degrade toluene and other mono-aromatic hydrocarbons (Ref.).
        - Thauera Gram-negative, rod-shaped bacteria able to anaerobically oxidize and degrade toluene (Ref.).
- Delta-proteobacteria Represented by morphologically diverse, anaerobic sulfidogens; some members of this group are considered bacterial predators, having bacteriolytic properties.
    - Geobacteraceae
        - Geobacter Anaerobic, metal-reducing bacteria in the family Geobacteraceae. They have the ability to oxidize a variety of organic compounds, including aromatic hydrocarbons (Ref.).
    - Desulfobacteraceae
        - Desulfobacterium Anaerobic, metabolizes C_{12}-C_{20} alkanes (Ref.).
        - Desulfobacula Anaerobic, metabolizes toluene and benzene (Ref.).
        - Desulfotignum A Gram-negative, sulphate-reducing bacterium (Ref.).
- Epsilon-proteobacteria Consists of chemoorganotrophs usually associated with the digestive system of humans and animals.
- Gamma-proteobacteria Comprised of facultatively anaerobic and fermentative gram-negative bacteria.
    - Piscirickettsiaceae

        - Cycloclasticus Marine bacteria; play a major role in degrading polycyclic hydrocarbons (PAH) from crude oil in marine environment (Ref.).
    - Pseudomonadaceae
        - Pseudomonas Numerous strains are most studied oil biodegraders; many strains are patented and are included in commercial bioremediation mixtures (Ref.).
    - Alteromonadaceae
        - Marinobacter Implicated in degrading polycyclic hydrocarbons (PAH) and other environmental pollutants (Ref.).
    - Pseudoalteromonadaceae
        - Pseudoalteromonas Marine oil-degrading bacteria (Ref.).
    - Pasteurellaceae
        - Pasteurella Was shown to degrade fluoranthene (Ref.).
    - Shewanellaceae
        - Shewanella Marine organisms frequenly isolated from oil-contaminated sites (Ref.).
    - Moraxellaceae
        - Acinetobacter Abilities for bioremediation of oil were documented (Ref.).
        - Moraxella Plasmid-mediated degradation of hydroxylated, methoxylated, and carboxylated benzene derivatives in *Moraxella* spp. were documented (Ref.).
    - Halomonadaceae
        - Halomonas Synonym *Deleya*; isolated from oil-contaminated soils (Ref.).
    - Alcanivoracaceae
        - Alcanivorax Present in un-polluted *sea water* in low numbers; principal carbon and energy sources are linear-chain alkanes and their derivatives (Ref.).
    - Oceanospirillaceae
        - Thalassolituus Marine hydrocarbonoclastic alkane-degrading bacteria (Ref.).
        - Oleispira Marine hydrocarbonoclastic bacteria (Ref.).
        - Neptunomonas Marine hydrocarbonoclastic bacteria (Ref.).
    - Oleiphilaceae

        - Oleiphilus Marine obligate hydrocarbon-degrading bacteria (Ref.).
    - Xanthomonadaceae
        - Rhodanobacter *Rhodanobacter* spp. is capable of utilizing benzo[a]pyrene (BaP) (Ref.).
        - Stenotrophomonas *S. maltophilia* is capable of utilizing various polycyclic aromatic hydrocarbons (PAH) (Ref.).
        - Xanthomonas Produce a yellow pigment; some species are pathogenic to plants. Biodegradation of complex polycyclic aromatic hydrocarbons was studied (Ref.).
        - Arenimonas Was isolated on nutrient agar from a soil sample collected from an oil-contaminated site (Ref.).
- Zetaproteobacteria

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