ODOR EMISSION CONTROL

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Keywords: Biofilter, Chemoreceptor, Cutaneous, Dilution, Gustatory (taste) sense, Hearing, Masking, Mechanoreceptors, Nociceptors, Odor, Olfactory sense, Sense, Smell, Taste, Thermoreceptors, Touch.

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Summary

Historically, human senses at large and olfactory capacity in particular have been the topic of much scientific speculation, but even today the precise mechanisms of chemoreception for smell and taste are still unknown. This considerably complicates any attempt towards regulation, analysis, or control of smell problems arising around various kinds of enterprise, as well as the difficulty of identification of sources. Attempts to relate odors to chemical structures or to other general or physical characteristics of odorous chemicals have not succeeded.

Odor problems should be tackled only after a thorough study of their sources. A suitable strategy is based on:

- Prevention at the source, e.g. by avoiding putrefaction or by containment;
- Treatment by thermal or catalytic combustion, adsorption on activated carbon, physical or chemical absorption, trickle bed filter biodegradation...
- Dispersion or masking.

1. Human Senses and Smell

1.1. Main Aspects

The study of **human senses** has always inspired numerous different specialists: philosophers, psychologists, physicians, anatomists, physical scientists, physiologists, and many others. Some early work was anatomical, an approach that continues to be fruitful. Physical scientists have contributed to an understanding of the nature of stimulus energies (e.g., acoustic, photic, thermal, mechanical, chemical). Physiologists have probed electrical signals generated by sensory cells and afferent nerve fibers and provided a biophysical analysis of sensory mechanisms. Psychophysics has studied the inner, subjective aspects of sensation in terms of outer, objective stimuli. A classical approach involves the monitoring of people's sensations and of their ability, for example, to match tones of equal loudness, to detect stimulus differences, and to estimate sensory magnitude or intensity under conditions of controlled stimulation.

Odors can be regarded in the first place as a social, psychological and aesthetic problem, rather than as a toxicity or environmental issue. Inhabitants living close to a smelly factory, a sewage treatment station, or a composting plant, may be annoyed and alarmed sometimes by the occurrence of smells, but the people working there regard the problem as minor and the situation as acceptable.

Smell perception and the resulting hindrance follow a series of events, including smell generation – transport – dilution – immission. Perception in its own right judges the kind, intensity or concentration, associated emotion, and acceptance of the smell. Smelly compounds as a rule are volatile organic compounds, composed of the elements **C**arbon, **H**ydrogen, (often) **O**xygen, **S**ulfur, **N**itrogen and Halogens (**C**h**l**orine, **Br**omine, **I**odine and **F**luorine). Although chemical analysis is capable of identifying and quantifying individual smell compounds at a level of μg or even ng per normal cubic meter (Nm^3), quite often the human nose is still much more sensitive than the best performing analyzer, given the very low odor thresholds allowing the perception of certain compounds.

Given these low thresholds it is important to treat the smell problems systematically and thoroughly. Often, the solution selected fails to solve the problem, either because the remedy is insufficiently effective, or because it targeted the wrong smell problem. There are several technical strategies for developing solutions to the average smell problem, mainly: (1) prevention, (2) treatment, and (3) dilution. Prevention generally relates to the prevention of fermentation, biological breakdown, or putrefaction of 'dead' organic matter. Proteins in particular give rise to stench. Treatment consists of thermal or catalytic combustion, adsorption, generally on activated carbon, absorption in various scrubbing liquors (often acidic/basic, or oxidizing/reducing) or in the slimy mass growing on the contact materials of a biofilter. Odor masking is not really state-of-the-art as yet. Dilution may help at times, or make things even worse.

1.2. Generation and Spreading

As a first step an activity emits compounds with a low odor threshold:

- as a main or a by-product of a chemical process,
- from the thermal or biodegradation of organic materials, or
- from leaks in process plant.

Some examples are:

- The petrochemical production of mercaptans or of alkyl amines, two groups of chemicals characterized by extremely low odor thresholds,
- Oil refining (mercaptans and disulfides occur in crude oil),
- Coking of coal, forming a wide range of aromatic or cyclic products, including pyridine and thiophene derivatives,
- The Kraft process of paper pulp manufacturing, cooking wood chips in sulfate liquors with concomitant mercaptan formation,
- Torrefaction of coffee, tea, chicory, and other vegetal materials,
- Biodegradation of proteins, which generally leads to really pestilential smells, e.g. in slaughterhouses, animal rendering, fish processing, maggot breeding, leather tanneries, etc.

Also smells from household refuse, composting, sewage, gasoline, and most solvents are easily distinguishable.

Secondly, the odor slowly spreads from its original source, gradually carried away by advection, i.e. the horizontal flow of ambient air, polluted in this process. Depending on the level of atmospheric stability, the odor threshold, and the initial concentration it is diluted to a large (at least by a factor 10^4) or even very large extent (by more than a factor 10^5), but may still be smelled at a distance of 10, 100, 1000 meter and beyond. Such **spreading of smells** causes discomfort; its perception and extent depend on ambient conditions and timing: at nighttime there is much more atmospheric stability than on a windy day, and the level of dilution will be much lower, hence the stench more concentrated. Also perception is variable. Generally, the workforce in a slaughterhouse gets soon used to the smell of dead animal corpses, and considers it as part of the job. People are much more tolerant on their way to work, than at leisure. On a sunny summer day, people tend to live outside, and be more exposed than on a cold, rainy day, when all windows remain closed. People strongly object that stench prevents them from sitting in their garden, or opening their window at night.

At this receiving end, detection takes place in the "*regio olfactoria*" of the nose, and a signal is sent to the brains. Interpretation follows almost immediately and leads to action, such as an immediate sense of discomfort, danger, or other sensations, causing flight, anger, or even pleasure (the smell of food for those hungry).

Smells are difficult to evaluate in a neutral, distant and objective manner, because of intrinsic variability in time and perception. Nevertheless, even a rare, but periodically occurring smell is often profoundly disliked and regarded as a serious problem, causing strong public action and demands for enterprises or activities to be transferred elsewhere.

2. The Human Senses

2.1. Basic Principles and Domain of Action

Senses play an important role in human life and pleasure and are essential in communication, yet their use is based on only a few and highly specific physicochemical interactions. A **Sense** is a bodily faculty by which a sensation is roused, e.g. sight, hearing, smell, taste, touch. Other senses include the kinesthetic (motion) and the vestibular sense (equilibrium).

In the wide range of electromagnetic waves, only a small band of 380-780 nm can be perceived by **eyesight**. The latter is capable of sharply visualizing objects and landscapes, even over enormous distances, far away in stellar-space.

Hearing is based on the perception of minute periodic variations in air pressure, caused by "sound". Since noise is easily spread, hearing is not as sharp as vision is. On the other hand sound can be observed from only 16 Hz to as much as 20,000 Hz, a span of more than 10 octaves (a rise of one octave means a doubling of the frequency). Moreover, a sound can be decomposed and analyzed, which allows the recognition of distinct musical instruments.

Touching allows the skin to register pressure, temperature or humidity, upon the direct contact of an object in the air, or water. Also radiant heat is felt.

The senses, **taste and smell**, are more chemical in nature. Taste leaves different impressions: sweet, acidic, salty, bitter, and is much enhanced by smell, the feel (hot, cold, hard, soft, etc.).

Finally, **smell** reacts possibly to voltaic compounds that either are inhaled through the nostrils, or disengage during the chewing of food. Thus, smell is essential in the tasting of food, whether for enjoying it or providing a warning there is something wrong with it. For animals smell helps in identifying a potential sexual partner, a fire, or pestilential situations. Some hazardous chemicals are easily identified by their smell: this is the case for ammonia, amines, sulfur dioxide, hydrogen sulfide, and mercaptans, but unfortunately not for carbon monoxide or by all (anosmia). Moreover, there is no relation whatsoever between detection threshold and the lethality of a compound, as expressed by a 50 percent Lethality Concentration LC_{50}, a Maximum Allowable Concentration MAC, or another limit value addressing toxicological impacts.

2.2. Sensory Systems, Receptors, and Nerves

Humans have several types of sensory nerves: photoreceptors (for light), mechanoreceptors (for touch, sound, and equilibrium), chemoreceptors (for smell and taste), thermoreceptors (for heat), and nociceptors (for pain). Classification of sensory systems is by type of stimulus. Each sense cell is responsive to one sort of energy change and can cause only one sensation, though the intensity of sensation depends on the nerve's threshold value. Other organisms are also able to detect different forms of stimuli.

The sense organs contain receptor cells especially sensitive to one type of stimuli and often located at a membrane in the body that receives a given stimulus (e.g., light receptors near the retina of the eye). Primary sense cells are often connected to secondary, ingoing nerve cells that carry impulses along threadlike **axons**, appendages of the nerve cell which carries signals under the form of nerve impulses. **Afferent nerves** lead to deeper, specialized parts in the brain and eventually to the cerebral cortex. **Chemoreceptors** are specialized cells that convert (transduce) the immediate effects of chemical substances into nerve impulses. A nerve cell (neuron) is called a **primary receptor**; a cell that responds to stimulation by inducing activity in an adjacent nerve cell is called a **secondary receptor**.

Distinction is made in **taste** (gustatory) receptors, as found in taste buds on the tongue; and **smell** (olfactory) receptors, embedded high in the lining (epithelium) of the nasal cavity. Gustatory receptors respond to direct contact with water-soluble materials (e.g., salt) and olfactory receptors to generally water-insoluble, vaporous materials that may even arise from a distant source. Many authorities prefer to regard smell as distance chemoreception and taste as contact chemoreception.

Odorous molecules may be carried to the olfactory region by slight eddies in the air during quiet breathing, but vigorous sniffing brings a surge into the olfactory region. Blocking the nasal passages mechanically, as when membranes are congested by infection may impair odor sensitivity. In vertebrates (such as humans), olfactory stimulation occurs only after the odor molecule is dissolved in the mucus that covers the olfactory membrane. In spite of the wide biological gap between them, odor sensitivity of humans and that of insects display certain similarities of mechanism, but both are as yet poorly understood.

2.3. Touch, Taste, and Smell

Cutaneous senses include a perception of or sensitivity to temperature, pressure, and pain; different areas of the skin are particularly sensitive.

Gustatory sense. Papillae or taste buds consist of cuplike structures that are distributed throughout all areas of the tongue, and in adjacent structures of the palate and throat. Each taste bud contains 50 to 75 receptor cells that are always in different stages of a 7 to 10-day regenerative cycle.

Olfactory sense. In mammals olfactory receptors are found high in the nasal cavity. The end of each receptor narrows to a fine nerve fiber, and all the nerve fibers lead to the olfactory bulb of the brain. The olfactory bulb ends in a number of glomeruli, each of which directs stimuli from receptors to specialized olfactory areas at the base of the brain.

There are also fibers that cross over from one olfactory bulb to the other. When the olfactory bulbs are removed by surgery, the individual's ability to discriminate odors is lost; details of the architecture of higher brain centers for smell are still unclear.

Olfaction depends on chemically sensitive nerves ending in the lining (epithelium) of the nasal cavity. The olfactory membrane in humans covers about 2.5 square centimeters on each side of the inner nose. The olfactory sense receptor is a long thin cell ending in several delicate hairs (cilia) that project into and through the mucus covering the nasal epithelium or lining. Electron microscope photographs show from six to 12 olfactory cilia per cell. The end of each receptor narrows to a fine nerve fiber, which, along with many others, enters the olfactory bulb of the brain through a fine channel in the bony roof of the nasal cavity.

Pain endings of the trigeminal nerve fibers are widely distributed throughout the human nasal cavity, including the olfactory region. Relatively mild odorants, such as orange oil, as well as the more obvious irritants, such as ammonia, stimulate such free nerve endings as well as the olfactory receptors.

Figure 1 shows a cross-section of the organs related to olfaction.

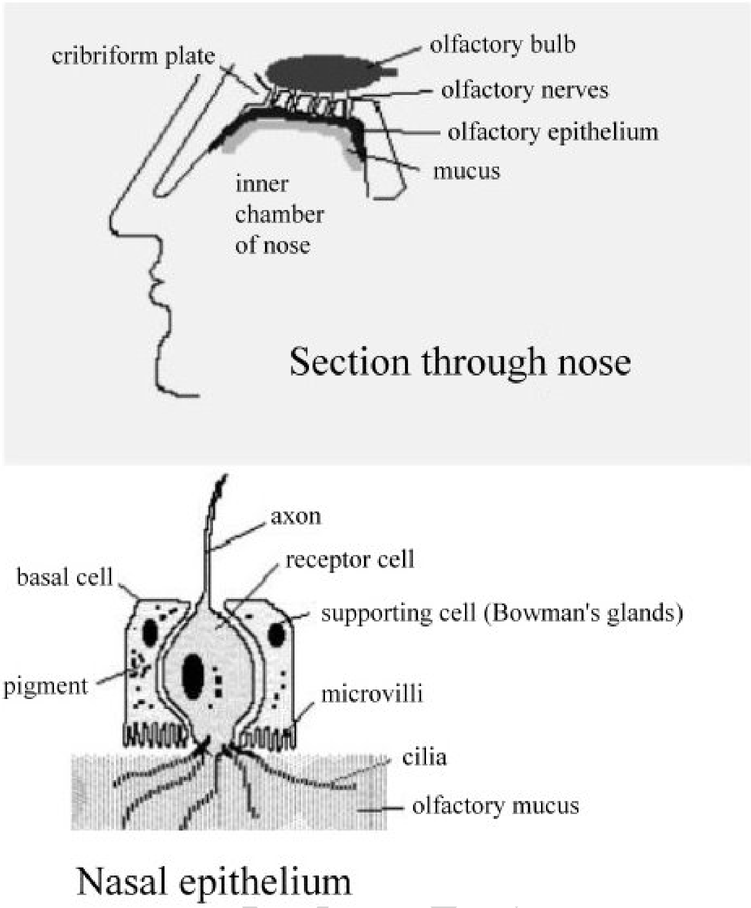

Figure 1: Cross-section of the Organs related to Olfaction

2.4. Smells and Odors

Smell (Olfaction) is the detection and identification of airborne chemicals by sensory organs.

Odor is the property of certain substances, often in very small concentrations, to stimulate chemical sense receptors that sample the air or water surrounding humans or animals. Some simple smells are often associated to one particular compound, e.g. rotten eggs and H_2S. A pig sty, a cattle sty, or a horse sty all have readily distinctive, but complex smells representing a cocktail of hundreds of compounds, many of which without a marked smell or even exhibiting, alone, a pleasant one. It is still unknown whether a characteristic smell is due to a particular product proper, or to a possibly unidentified small impurity normally accompanying its synthesis or presence. Chemically analogous compounds may have a similar smell (aromatics), but also a rather distinct one.

3. Generation and Monitoring of Odors

3.1. Odors: Origins – Perception - Adaptation

3.1.1. Natural and Thermal Odorous Processes

Odors are generated in a variety of natural and thermal processes, e.g. putrefaction, fermentation, wastewater treatment, baking, cooking, roasting, torrefaction, thermal decomposition, or occur by the application and use of odorous products such as solvents, fuels, or perfumes. Some substances have a characteristic smell. Most of these are organic compounds, but a limited number of inorganic compounds also exhibit a smell, e.g. iodine, chlorine, ozone, ammonia, hydrogen sulfide, sulfur dioxide. The simplest organic molecules, the paraffins, have little or no smell, at most that of a burning candle. The introduction into the molecule of heteroatoms, more in particular of oxygen, sulfur, nitrogen or halogens, profoundly alters the picture. There is little logic in smells. Ozone for instance smells of garlic, but has no link with this smelly vegetable.

3.1.2. Threshold Values

Olfaction is said to be 10,000 times as sensitive as taste. A human **threshold value** for a well-known odorant as ethyl mercaptan (found in rotten meat) has been cited in the range of ng per m^3 of air. For mercaptans (present in skunk odorant, effluent vapors from Kraft wood chips cooking and willfully added to natural gas, for rendering it readily detectable and providing a warning for the explosion danger associated with its presence in air), only about 40 receptor cells in the human nose need being stimulated by no more than nine molecules each to give a detectable odor sensation.

Many aldehydes and ketones have pleasant, fruity aromas, and these compounds are frequently responsible for the flavor and smell of fruits and vegetables. Conversely, the disagreeable smell of fat remelting and frying is also associated with aldehydes. Benzaldehyde is an aromatic aldehyde and imparts much of the aroma to cherries and almonds. Acetone is a useful solvent for organic compounds with a characteristic smell. Butanedione, a ketone with two carbonyl groups, is partially responsible for the odor of cheeses.

3.1.3. Sensitivity and Adaptation

Hunting dogs can follow a spoor most easily when high humidity retards evaporation and dissipation of the odor trail. Changes in sensitivity are reported to occur in women during the menstrual cycle, particularly in regard to certain odorants (steroids) related to sex hormones. Olfactory sensitivity is said to become more acute during hunger. Human **adaptation** to odors is so striking that the stench of a slaughterhouse or chemical laboratory ceases to be a nuisance after a few minutes have passed. Olfactory adaptation, as measured by a rise in threshold, is especially pronounced for stronger odors. Cross adaptation (between different odors) may take place; thus, eucalyptus oil may be difficult to detect after one becomes adapted to the smell of camphor.

Adaptation long was regarded solely as the result of changes in the olfactory receptor; however, electrical recordings show that the receptor cells in the nose seem to adapt only partially. Rhythmic discharges continue in the olfactory bulb long after the experimenter ceases to detect the odor that is stimulating the experimental animal. Apparently, some olfactory adaptation may occur in the brain as well as in the sense organ.

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Biographical Sketch

Alfons Buekens was born in Aalst, Belgium; he obtained his M.Sc. (1964) and his Ph.D (1967) at Ghent University (RUG) and received the K.V.I.V.-Award (1965), the Robert De Keyser Award (Belgian Shell Co., 1968), the Körber Foundation Award (1988) and the Coca Cola Foundation Award (1989). Dr. Buekens was full professor at the Vrije Universiteit Brussel (VUB), since 2002 emeritus. He lectured in Ankara, Cochabamba, Delft, Essen, Sofia, Surabaya, and was in 2002 and 2003 Invited Professor at the Tohoku University of Sendai.

Since 1976 he acted as an Environmental Consultant for the European Union, for UNIDO and WHO and as an Advisor to Forschungszentrum Karlsruhe, T.N.O. and VITO. For 25 years, he advised the major industrial Belgian Bank and conducted more than 600 audits of enterprise.

Main activities are in thermal and catalytic processes, waste management, and flue gas cleaning, with emphasis on heavy metals, dioxins, and other semi-volatiles. He coordinated diverse national and international research projects (Acronyms Cycleplast, Upcycle, and Minidip). Dr. Buekens is author of one book, edited several books and a Technical Encyclopedia and authored more than 90 scientific publications in refereed journals and more than 150 presentations at international congresses. He is a member of Editorial Boards for different journals and book series.

He played a role in the foundation of the Flemish Waste Management Authority O.V.A.M., of a hazardous waste enterprise INDAVER, and the Environmental Protection Agency B.I.M./I.B.G.E. He was principal ministerial advisor in Brussels for matters regarding Environment, Housing, and Classified Enterprise (1989). Since 1970 he has been a Member of the Board of the Belgian Consumer Association and of Conseur, grouping more than a million members in Belgium, Italy, Portugal, and Spain.

He is licensed expert for conducting Environmental Impact Assessments (Air, Water, Soil) and Safety Studies regarding large accidents (Seveso Directive).