The Quality Candle

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THE QUALITY CANDLE

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Abstract

This article gives an overview and description of the raw materials and additives that are used for the manufacture of candles and explains the combustion process in the candle flame. Starting with the definition and classification of candles the criteria are presented which are crucial for the safe handling of candles i.e. ensuring they are harmless in relation to both people and the environment. The structure and content of a proposed European quality standard for candles are derived from these criteria.

1 Introduction

Candles have accompanied mankind for more than 2000 years. Besides their liturgical relevance, candles were predominantly used as a source of light and in the early history of their development were the better alternative to pinewood spill (the chip from resinified pinewood)

Closely connected to the more than 2000 year development history of the candle are the efforts to improve its quality. Beeswax candles had been developed by the Romans to such an extent that by approximately the middle of the second century A.D. they could be burnt in a closed room without sooting annoyingly or excessively. Beeswax candles showed significant advantages when compared to tallow candles. The latter had a rancid odour and smoked and sooted whilst burning.

It was only as late as the mid nineteenth century that stearin and paraffin wax offered further high quality raw materials available for the manufacture of candles alongside beeswax. During the same period decisive improvements were made to wicks, in particular the braiding techniques and chemical treatments. So further prerequisites for candles that burnt well were fulfilled and Goethe's dream ´´ I know not what you could invent better than candles that burn without smoking`` could be realised [1].

Figure 1: Impressive Atmosphere by Candlelight

Picture: Grimm Agency

The myth surrounding the candle remains even today, although numerous and various types of light are available to us since the invention of electric light and its introduction into our daily lives. Candlelight is still associated with a festively laid table, a pleasant coffee morning or idyllic romantic hours spent together (Figure 1). Obviously a candle that burns well and does not soot is a must for enjoying such occasions. Sooting and dripping are the decisive quality criteria of the consumer when judging candles.

Further to this and given the environmental awareness of today the candle, as a product with an open flame, is naturally drawn into discussions concerning the possible negative effects on humans and nature by potentially harmful substances. The consumer of today has the right to demand high quality products, the use of which does not present a hazard to people or the environment.

Past and present discussions about potentially harmful substances in the materials used for the manufacture of candles, coupled with talk of emissions hazardous to health which result when the candle is burnt, have led to the partial insecurity of the consumer. For this reason national and international candle associations have requested that numerous scientific investigations be carried out by renowned, independent institutes, the results of which have confirmed that high quality candles are quite safe to burn [2, 3, 4, 5].

Traditional craftsmanship, training and the passing down of experience all go together to guarantee the production of high quality candles by specialized candle companies. The quality of candles manufactured industrially is also checked and monitored constantly. To this end the German Candlemakers' Association has defined standards for candle quality as well as for additives and raw materials used in their production. These requirements have been combined and published in the *RAL Quality Mark 041 Candles* [6] (RAL Gütezeichen Kerze).

Quality standards are not only becoming more meaningful in Germany but also throughout Europe.
A visible confirmation of tested quality is the quality mark for candles (Figure 2).

GÜTEZEICHEN
RAL KERZEN

Figure 2: RAL Quality Mark

2 Raw Materials and Additives for Manufacturing Candles

2.1 Raw Materials

Candles are made up of one or more wicks surrounded by a solid material, the wax, which can be burnt. The term ‘wax’ coves a variety of different products of mineral, animal or vegetable origin which have a number of common physical properties (Figure 3).

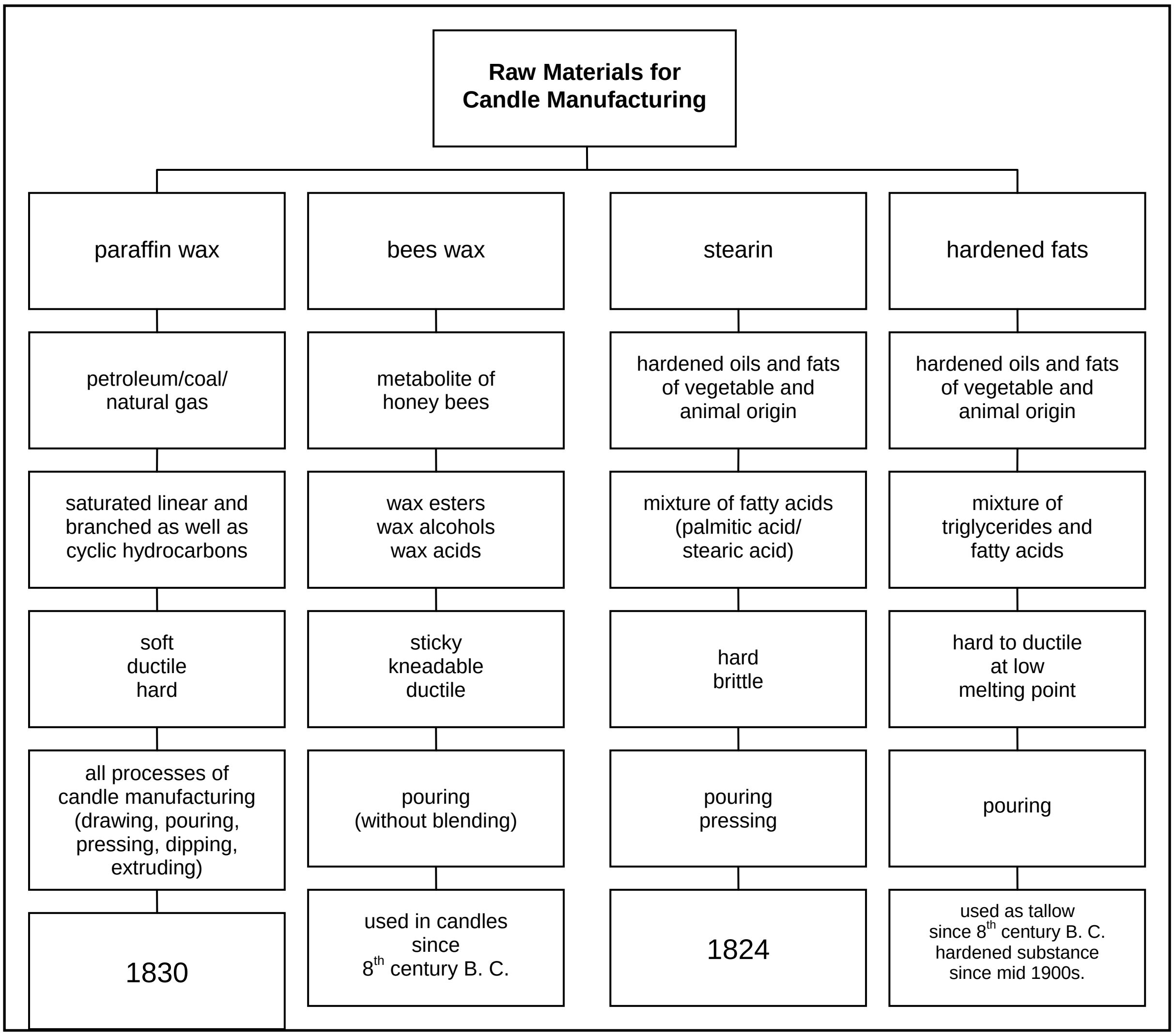


Figure 3: Raw Materials for Manufacturing Candles

If we look at candle production today the main burning materials used are paraffin wax, stearin and beeswax. Further to these hardened vegetable oils, solid vegetable fats and fats of animal origin are used in sanctuary candles, oil lights and composition oil lights. Hardened waxes are increasingly used in the production of candles to justify claims of ´´natural`` and ´´renewable``.

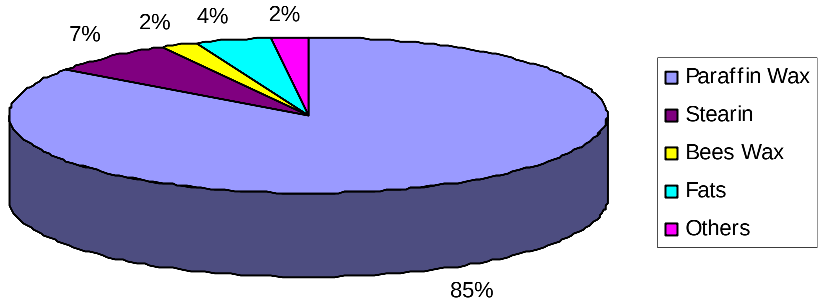


Figure 4: Share of Raw Materials for Candles

Price and availability of raw materials, how well these materials lend themselves to existing candle production methods, as well as their influence on the product and its performance characteristics (e.g. burning) are decisive for their selection in modern candle production.

2.1.1 Paraffin Waxes

Paraffin wax is a complex composition of hydrocarbons which are solid at room temperature and which have a wax-like consistency. We can differentiate here between straight chain and branched chain alkyl-substituted cyclic hydrocarbons. As well as being derived from mineral oil paraffin waxes can also be produced by Fischer-Tropsch-synthesis. Paraffin waxes used in candle production today are mainly derived from the fossil fuel crude oil.

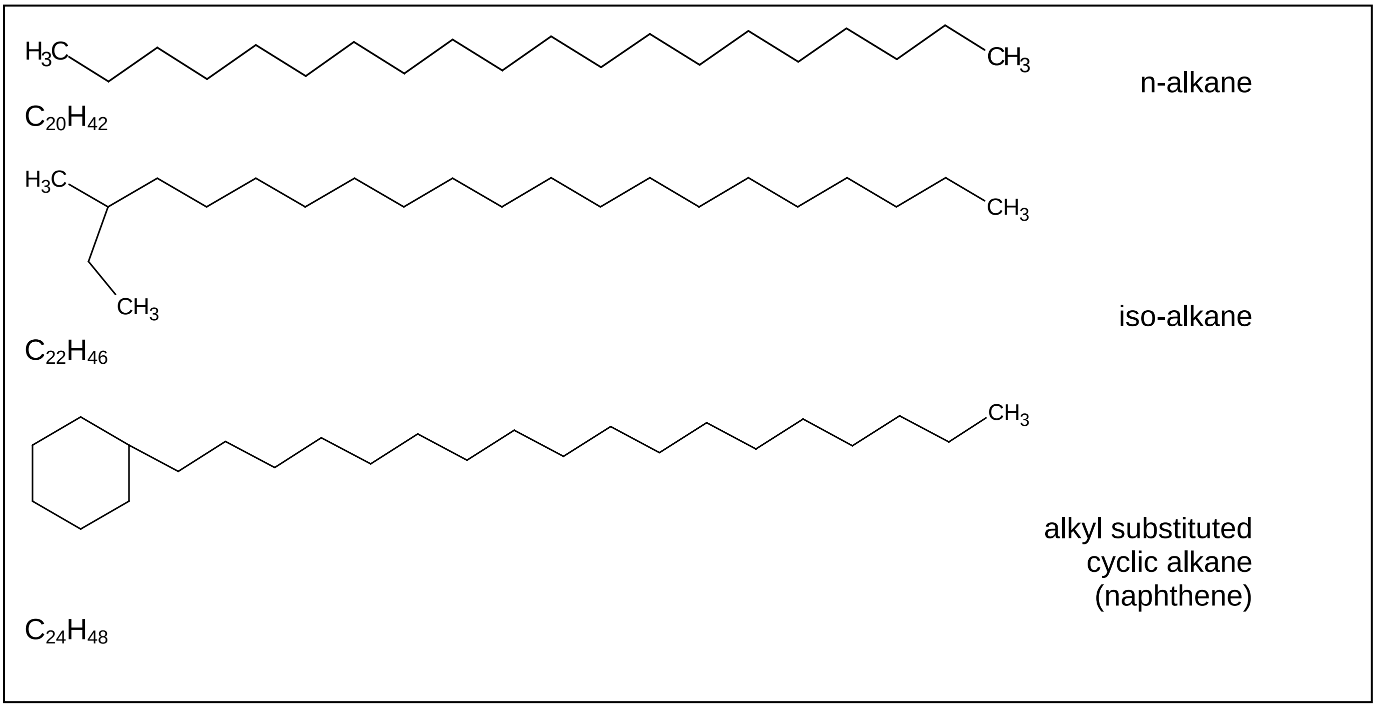


Figure 5: Paraffin Wax; Examples of Chemical Structures

In the distillation of mineral oils different distillation fractions are separated, according to their various boiling points, from which slack waxes are obtained. With the aid of a sophisticated sequence of production steps – filtration, de-oiling, hydrogenation – they are processed to form highly refined paraffin waxes.

These refined paraffin waxes are subject to constant quality controls and are toxicologically harmless. Their environmentally compatible properties are characterised by biodegradability as well as the lack of eco-toxic and bio-accumulating properties.

Paraffin waxes which are usable in the production of candles congeal between 45 °C and 70 °C. Further important differentiating criteria are hardness, oil content and viscosity.
Due to their chemical and physical properties paraffin waxes are suitable for all candle manufacturing processes.

In close co-operation with the candle manufacturer the paraffin wax producer can select the optimal raw materials and settings of production equipment for each case in question – candle type and production process – in order to specify the most suitable paraffin waxes.

2.1.2 Beeswax

Beeswax, the oldest known raw material for candles, is a metabolic product of the honeybee. The wax is exuded from glands on the abdomen of the worker bees and used to make the honeycomb. The wax acquires its colour and pleasant smell over a period of time through contact with honey and pollen. The availability of this raw material is naturally limited.

Beeswax is a mixture of:

70 %	esters of long chain wax alcohols (C24 - C44) with carbon acids (C16/C18)
13-18 %	hydrocarbons (C25 - C35)
10-15 %	free wax acids (C24 - C32)
1 %	free wax alcohols (C34 - C36)

(Figure 6).The melting point of beeswax is about 65 °C. Further characteristics are the acid value (17 – 24 mg KOH/g), the saponification value (87 – 104 mg KOH/g) and the ester value (70 – 80 mg KOH/g). Its colour ranges from yellow, light and dark green through red/yellow to dark brown. Viewed in cross section it has a dull, shell like appearance with a fine particle structure. It is highly malleable and has a good degree of plasticity and is sticky when warmed.

$H_{31}C_{15}-C(=O)-O-C_{30}H_{61}$

$C_{46}H_{92}O_2$

palmitic acid ester of myricyl alcohol

$H_{51}C_{25}-C(=O)-O-C_{30}H_{61}$

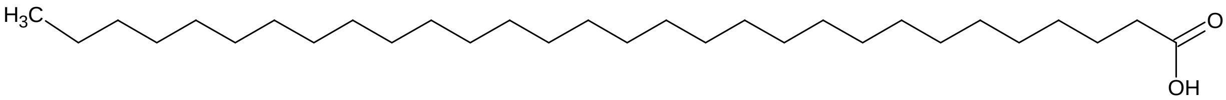
$C_{56}H_{112}O_2$

hexaeicosan acid ester of myricyl alcohol

$H_{31}C_{15}-C(=O)-O-C_{16}H_{33}$

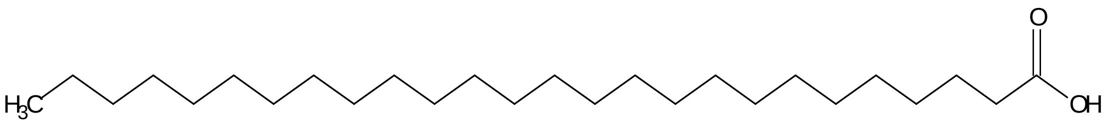
$C_{32}H_{64}O_2$

palmitic acid ester of cetyl alcohol



$C_{30}H_{60}O_2$

melissic acid



cerotinic acid

$C_{26}H_{52}O_2$

Figure 6: Beeswax; Chemical Structure, Formula

Natural beeswax contains a number of impurities which are removed by various purification methods. It is then usually bleached using Fuller's Earth or hydrogen peroxide. As colour and smell are partially lost in this process, colour and fragrance are added to the highly purified beeswax again for consumer reasons. Bleached beeswax is used for altar candles. It is also used as a blending component for wax compositions and, due to its malleability, for the production of wax slabs used for decorative purposes e.g. flowers, ribbons and other ornaments.

2.1.3 Stearin

Stearin (greek steer – tallum) is, in normal conditions, a solid, crystalline blend of various fatty acids mainly made up of palmitic acid and stearic acid. Although it has wax like properties it is not normally categorised as a wax.

The base products for the production of stearin are animal resp. vegetable fats and oils, whereby palm oil is the main vegetable raw material. Animal raw materials are mainly beef and pork tallow. Use is seldom made of fish oil or fish fat. Candle producers usually use vegetable based stearic acids nowadays.

In the base products, the fatty acids are bound to glycerine. These triglycerides are continuously split into fatty acids and glycerines in the presence of water. After the glycerine content has been removed, the cracked acids undergo the process steps of separation, hydrogenation, and fractionised distillation and are then mixed to different technical stearin blends. The individual stearin types can be differentiated by their ratio of palmitic acid to stearic acid (Figure 7).

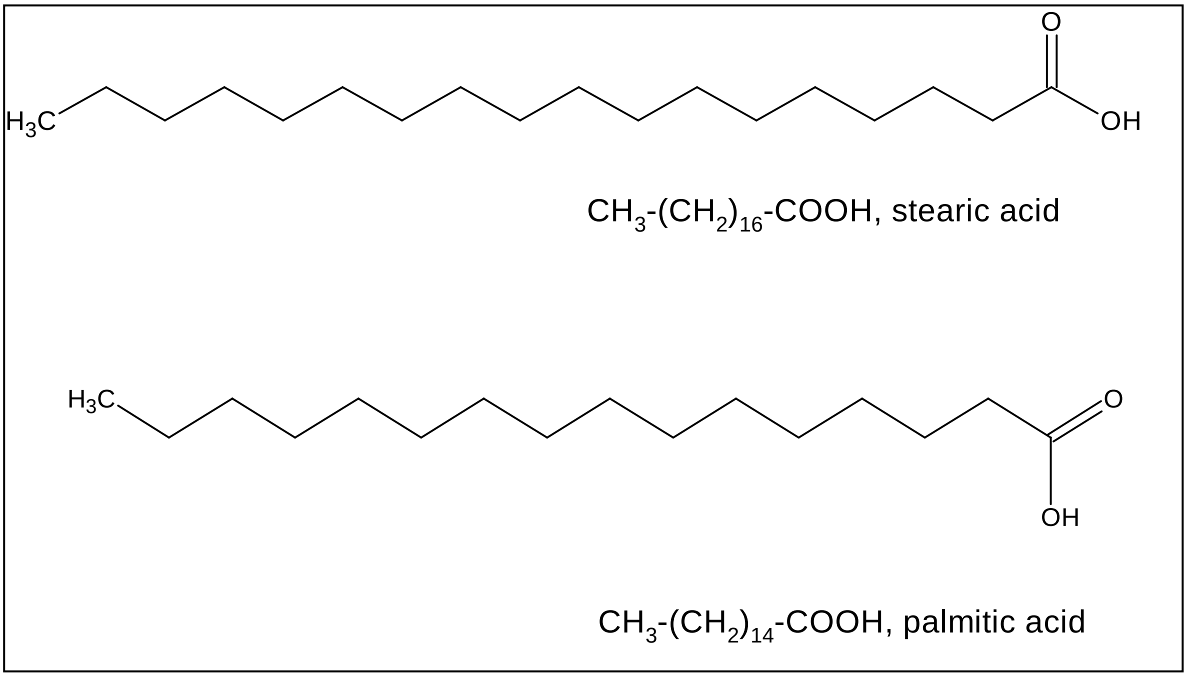


Figure 7: Stearin; Chemical Structure

Independent of the palmitic/stearic acid ratio, the stearins have differing crystallisation behaviours (macro- and microcrystalline structures). Contraction and the formation of decorative surface effects are inherent properties which emerge depending on the various applications.

The congealing point is within the range of 52 °C to 60 °C. Further important characteristics are those for acid, saponification and iodine value as well as the percentage of unsaponifiable matter.

A special characteristic of stearins is that the softening and melting points are almost identical whereas in paraffin waxes these points are approximately 15 °C apart. This is the reason for the excellent temperature stability of stearin candles. However, the lack of flexibility dictates that stearin candles have predominantly been produced by the pouring process to date. However, further development of candle production technology is making it increasingly possible to produce stearin candles by pressing.

2.1.4 Hardened Fats

Natural fats and oils are made up of blends of triglycerides with different fatty acids (Figure 8). According to the length of the chain and the degree of saturation (saturated, mono or polyunsaturated) these fatty acids are either solid, semi solid or oily substances.

Tallow was used in very early times for the production of candles. The production processes used in those days led to the production of poor quality candles (smoking, dripping, with an unpleasant odour). That is why tallow was quickly superseded by paraffin wax and stearin in the middle of the 19th century. The further technological development of reprocessing procedures for tallow allows products to be created which are gaining in significance in the candle industry today. Palm oil is again the most significant here as after pressing out, removal of mucilaginous substances and the subsequent hydrogenation (fat hardening) it can be used for white, sometimes very hard, candles. A further split into different fractions is possible following hydrogenation. A palm oil fraction with a congealing point of between 45 °C and 48 °C thus gained is known as palmitic stearin even though it is in actual fact a fat.

Typical characteristics for the fats are the congealing resp. melting points, the saponification number, the iodine number as well as the hardness and viscosity.

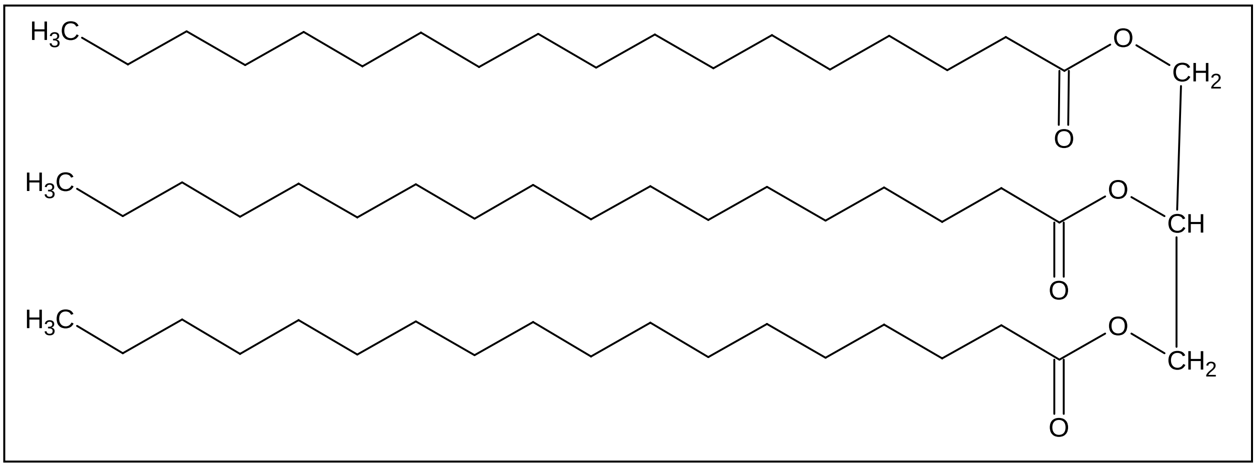


Figure 8: Hardened Fat; Chemical Structure

As well as their use in the church sector (grave lights, oil composition lights) hardened vegetable fats are being used more and more in candles destined for use in the home. Due to their superior ability to bind fragrances hardened fats are especially suitable for highly perfumed jar candles.

2.1.5 Comparison of Raw Materials

All the main raw materials can either be used either pure or in blends in candle production. The composition of candles should be recognizable for consumers. Due to the ease of working with it and its availability paraffin wax has by far the most significant position in candle production.

Paraffin wax, stearin, fat and beeswax – all basic raw materials for candle production – are natural elements which are reprocessed with such sophistication that they have the properties required. In such high quality products, the naturally occurring harmful substances are kept so low that they do not present any danger for people or the environment. The purity of the raw materials and products is constantly monitored with the aid of state of the art analytical procedures. Therefore, consumer safety does not depend on which of the above mentioned raw materials are used but on the purity of the raw material in question.

2.2 Additives

As well as the above mentioned main raw materials, a number of additives are used to compound candle materials. These are mainly synthetic waxes from the polymer-chemistry branch e.g. polyethylene waxes and copolymers as well as high melt Fischer-Tropsch paraffin waxes. To achieve special effects other natural waxes e.g. carnauba wax, montan wax etc. are employed as additives. Colours, lacquers and fragrances complete the range of materials used in candle production.

2.3 Wicks

In addition to the raw materials and additives the wick, often referred to as the soul of the candle, plays a central role when regarding candle quality. It has a decisive influence on the burning behaviour of the candle and is included in discussions about candle quality especially with regard to its composition and combustion products formed in/by it.

The wick is mainly made up of braided cotton threads which are usually treated with inorganic compositions. Long, fibrous cotton with a uniform structure produces the best results. The fibres have a major influence on capillary action, wick stance and ultimately the ability of the wick to self trim.
The inorganic elements of the wick treatment prevent after glow of the wick when it is extinguished. The formation of a crystal skeleton after the chemical treatment process increases the stability of the wick.

The strength and number of the fibres as well as the type of braiding (mainly differentiated between flat and round wicks) determine the capillary action and stability of the wick. The curve of the wick in the flame can be influenced by the introduction of special tension or stability threads.

The choice of wick and candle material used, together with the diameter of the candle, must complement each other optimally to ensure the ideal burning of the candle. The wick regulates the melting, absorption, evaporation and burning of the fuel used [7].

Figure 9: Wick Braiding Machine

3 Definition, Classification and Burning Behaviour of Candles

Parallel to knowledge regarding the origin and purity of the raw materials and additives used in candle production, it is important that an understanding of candle classification as well as the processes which take place in the flame is assured. These are prerequisites for sound, factual discussions concerning candle quality in conjunction with the preparation of quality standards. Focus is on the burning behaviour of the candle, as this is the quality ´experience` which is immediately visible to the consumer.

3.1 Definition of a Candle

In the universal lexicon of 1738 the candle is poetically defined as ´´ a wick of threads covered with tallow or wax which, when lit, casts a bright glow which lightens a dark place`` [8].

Figure 10: Drawing - W. Hogarth (1697-1764) [9]

Nowadays they are described much more soberly. Thus, candles are sources of light and have as a central feature one or more wicks surrounded by a solid fuel [10].

Both definitions, i.e. that of 1738 and RAL 040 A2 [10], clearly separate the term candle from oil lamps, oil or other flammable liquids in containers even when these resemble candles e.g. torches, sparklers and pinewood spill. This does not change the original common function of being a source of light, which is an important aspect in the context of the defining quality criteria.

The description of the solid fuel must be made more precisely today. As well as the temperature, e.g. room temperature of 25 °C, at which solidification is guaranteed, the burning of the wick is a key function. To date mainly waxes have been used (see point 2.1) but now the range is being extended through the introduction of new synthetic raw materials such as special polymers, polyamides etc. (see point 2.2).

Even though candles are used in many cases as decorative ornaments for rooms, the use as a source of light remains the ´real use` for the consumer. The criteria of the flammability of the wick makes special quality demands on the burning mass with relation to the burning process (temperature, combustion products).

3.2 Qualitative Classification of Candles

Even if candles are classified completely separately from other sources of light as a product, the classification can be sub-divided into numerous, vastly differing candle types.

Figure 11: Variety of Candles
Picture: from the Ebersbacher Wachswaren GmbH catalogue

Lastly the constantly increasing number of candle classifications makes this variety apparent. As the fantasy of candle developers, producers and traders is almost unlimited these classifications are not only suitable from a quality perspective. In the past attempts were made to define generally valid classifications. The most extensive of these attempts was carried out by Büll [11]. The most important main groups are (amongst others):

- Technological groups — raw materials (paraffin wax-, beeswax-, stearin-, composition candles) production processes (pouring, drawing, hand-dipped candles, pressing, extruding)
- Classification according to use: advent-, tree-, altar-, christening candles etc.
- Classification according to shape: ball-, taper-, square candle
- Historical art classification: antique-, baroque-, renaissance candles
- Design classification: coat of arms-, decoration-, figure candles

Tealights and other container candles are not included in these classifications which are mainly of a technical nature. For the above mentioned candle types the creation of light (flammability of the wick) is a chief differentiating characteristic.

Expansion of the candle definition is required here. The burning mass which is solid at room temperature can be either free standing or in a container, the German word 'Licht' = light is especially emphasised in the German names for the latter e.g. tea lights, grave lights.

This differentiation is important with regard to the quality demands that these products should fulfil.

Classification of candles/lights according to quality aspects must always be fixed from the consumer's point of view. Only then will it be possible to establish the different quality demands sensibly and to divide quality parameters into those which apply for all candles and those which represent specific demands for individual product groups. To this end the following classification has been suggested:

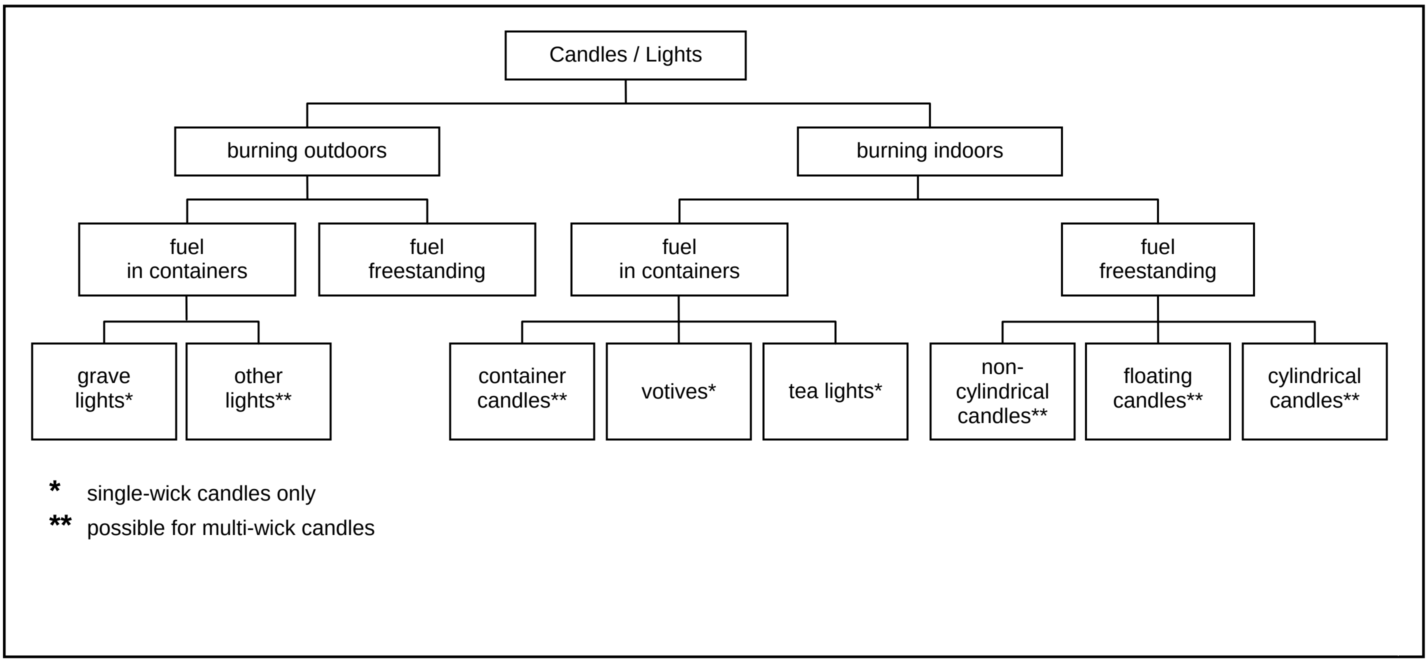


Figure 12: Classification of Candles

3.3 Physical and Chemical Processes within the Candle Flame

The English natural scientist M. Faraday was very intensively involved with the processes within the candle flame.

Figure 13: Michael Faraday (1791-1867)

During his lectures entitled "Lectures on the Chemical History of a Candle [12]" he classified the burning process of a candle as a microcosm and stated:
" There is not a law under which any part of this universe is governed which does not come into play and is touched upon in these phenomena. There is no better, there is no more open door by which you can enter into the study of natural philosophy than by considering the physical phenomena of a candle. ".
When a candle is burnt a whole number of chemical and physical processes take place which should be looked at more closely.

3.3.1 Fundamentals of the Combustion Process

The combustion process can be divided into the following phases:

1. Melting of the fuel
2. Transport of the fuel by the capillary action of the wick
3. Conversion of the liquid fuel into gas
4. Thermal decomposition (pyrolysis) of the fuel
5. Oxidisation of the pyrolysis products

From the energy balance point of view the combustion process can only take place if energy released by reaction (heat of combustion) is equal to, or preferably in excess of, that energy which is necessary to ignite further fuel particles.

Paraffin wax used in candles is solid at room temperature (25 °C). After ignition of the wick, the paraffin wax starts to melt due to the supply of ignition energy.
Further supply of energy results in vapourisation (gas phase or vapour phase) and subsequently in degradation (pyrolysis) into gaseous hydrocarbons, hydrocarbon fragments (radicals) and solid carbons. The light radiation of this zone is nothing else than the glowing of finely dispersed, solid carbon particles. The gaseous components and carbon particles are first mixed with oxygen in the burning zone. After the ignition temperature is reached and the mixture with oxygen complete, the actual combustion process takes place. Combustion heat is released and the reaction commences. Supply of external energy must be maintained until the minimum combustion temperature is reached. This variable period, during which an energy flow in terms of ignition energy is necessary, can be defined as a delay in ignition. Once the minimum combustion temperature is reached, enough combustion energy is released to allow an independent combustion process to continue unaided, without a further energy supply being necessary. The external energy required during this time can be defined as minimum ignition energy.

3.3.2 Flame Zones

When observing a candle flame the following schematic structure as shown in Figure 14 can be seen:

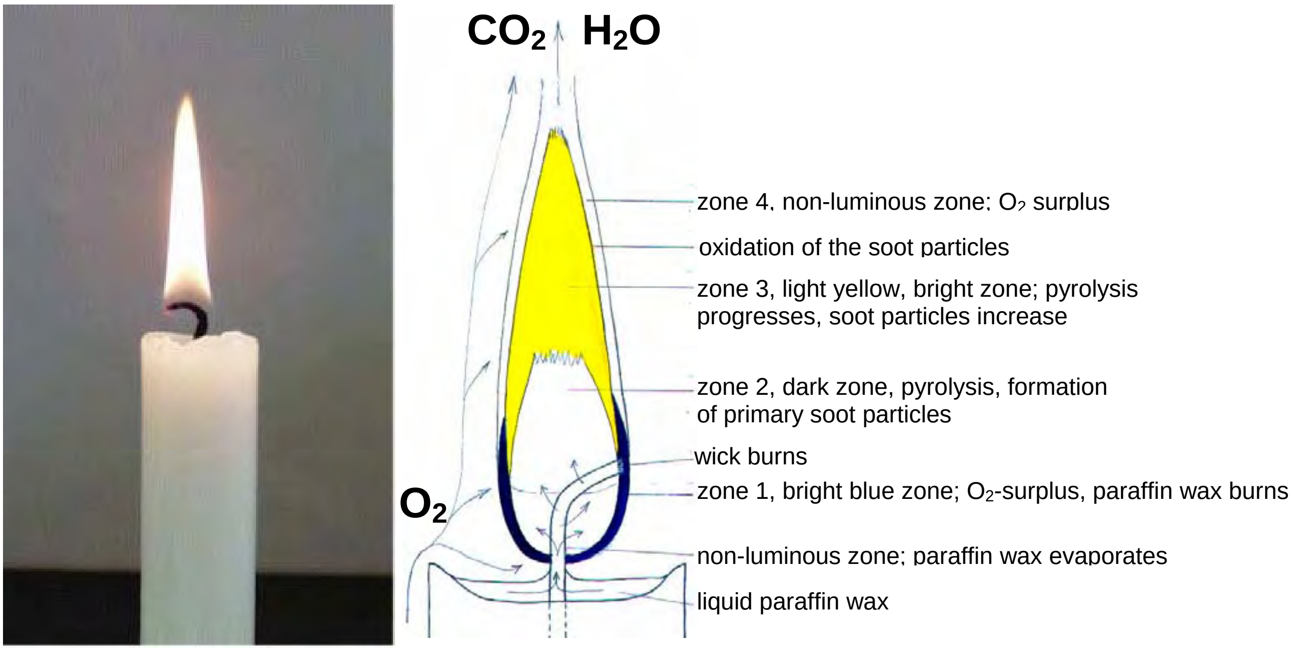


Figure 14: Flame Zones

The flame can be distinctly separated into four distinct zones:

Zone 1 (blue Zone): this zone surrounds the lower part of flame like a luminous, blue goblet. Surplus oxygen is present. Part of the fuel burns completely to water and carbon dioxide, without formation of carbon particles. The temperature is around 800 °C. Energy transfer by heat radiation below and beside this zone results in melting of the fuel and the formation of the burning bowl. The lower the melting point and the melting enthalpy of a fuel, the more liquid fuel collects.

Zone 2 (dark zone): this zone forms an ellipsoidal area, like a hollow within the lower third of the flame. This zone is characterised by a shortage of oxygen. The lower part of this zone, where the fuel evaporates from the wick, is dark. In the region directly adjacent to the wick the temperature is 600 °C. The viscosity and enthalpy of evaporation of the fuel are crucial for the fuel supply by the wick. In the outer, upper part of the dark zone pyrolysis (cracking) of the fuel begins due to the shortage of oxygen. Minute carbon particles are formed, the temperature is 1,000 °C.

Zone 3 (luminous zone): this zone has the shape of a yellow-white, luminous cone, which is hollow in the lower third. There is still insufficient oxygen available, thus pyrolysis continues. Larger carbon particles are produced, the glow of which results in light and heat radiation. The temperature is 1,200 °C. (see fig.14).

Zone 4 (the so-called **veil**)**:** the lower part of this zone overlaps with zone 1 and surrounds the flame as a non-luminous, hollow cone. Oxygen is present in excess and the temperature is 1,400 °C. At the boundary between zone 3 and 4, the carbon particles are burnt faster and more completely to carbon dioxide the smaller they are as long as the temperature is higher than 1,000 °C. If the temperature drops below this value, e.g. due to draughts, oxidisation of soot particles ceases, regardless of whether sufficient oxygen is available or not. This is why draughts result in soot emission by candle flames.

3.3.3 Combustion Process

The splitting up of paraffin wax chains takes place using the same mechanism as the pyrolysis (cracking) of petroleum naphtha. Naphtha cracking is the most widespread industrial process for producing ethylene, The process starts at a temperature between 800 °C and 900 °C with the homolytic dissociation of a C-C-bond resulting in two alkyl radicals. Each of these radicals will then eliminate an ethylene molecule and form a new radical with 2 carbon atoms less, which can again remove ethylene (β Degradation Rule). Thus the main process is a radical de-polymerisation of paraffin wax molecules. Via thermal dehydrogenation of ethylene (the temperature of the upper part of zone 2 is already 1,000 °C) acetylene is formed, which decomposes into carbon and hydrogen. Alkyl radicals are also able to react in other ways. As an example Figure 15 shows the elimination of an H-atom.

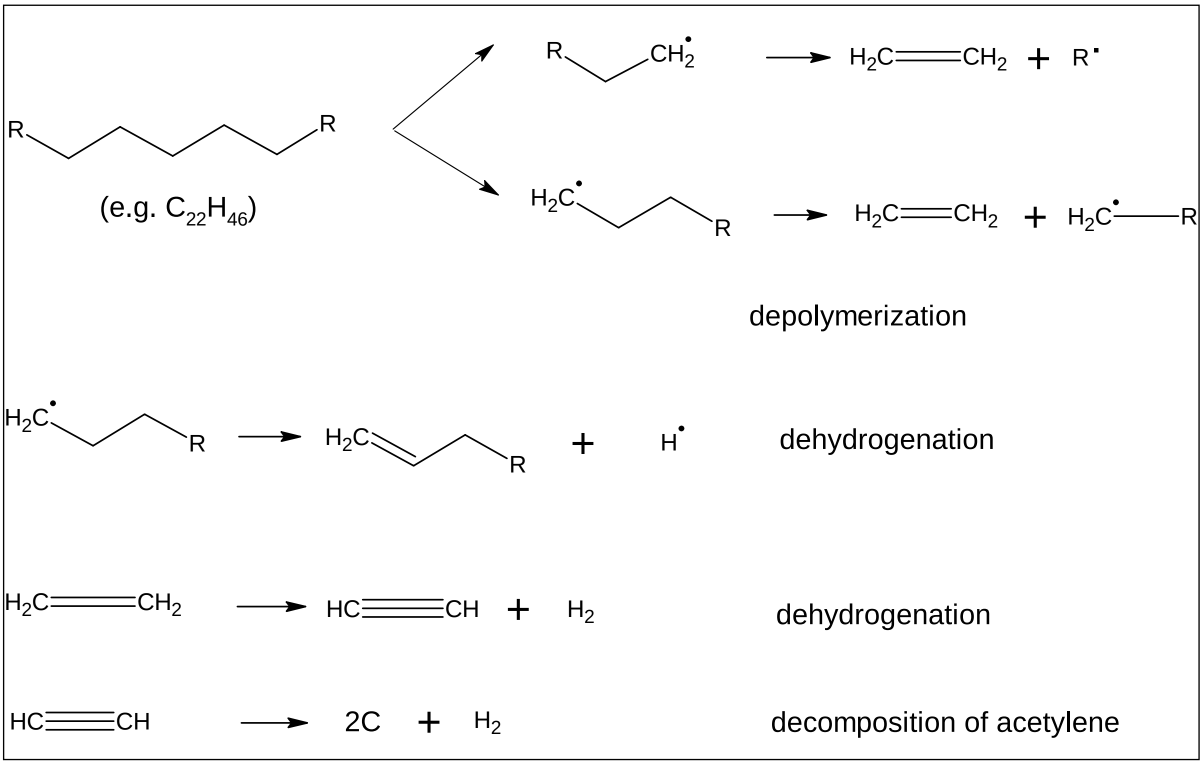


Figure 15: Mechanism of Chain Degradation Within the Flame

Depolymerisation and dehydrogenation are endothermic processes, thus heat energy is consumed. Nevertheless, the temperature within the candle flame increases from 800 °C in zone 1, through 1,000 °C to 1,300 °C in zone 3. The reason for is the combustion of hydrogen. From each C_2H_4-molecule two molecules of hydrogen are formed, which in turn split into four hydrogen atoms by thermal dissociation. By diffusion these will be transferred faster than the bigger alkyl radicals to the oxygen-rich rim of the zones, where they can start the branched chain reaction with oxygen molecules to form water. The combustion of hydrogen results in the heating of zones 2 and 3 such that the carbon particles reach incandescence. This heating is the requirement for their combustion between zones 3 and 4. The flame will emit soot if the generated energy is insufficient to heat the carbon particles above 1,000 °C.
This is the case, when an insufficient volume of hydrogen is formed per unit of time. Thus the carbon/hydrogen ratio of the fuel used plays a crucial role. Unsaturated hydrocarbons (e. g. aromatic compounds) which are present in unrefined / non - hydrogenated slack waxes, have a very high tendency to release soot. In addition the velocity of pyrolysis of alkanes decreases in the following order: primary > secondary > tertiary. High content of iso-paraffins or a high degree of branched molecules will decrease the flame temperature as well and could result in a higher tendency of the flame to soot.

4 Structure of Quality Standards

In the past there was no lack of attempts to specify qualitative requirements for candles. The tangible result of these efforts is the *RAL Quality Mark 041 Candles*. This quality standard, which was worked out on the initiative of the German Candle Manufacturers Association, merges quality requirements for candles and those for raw materials for the first time. Numerous consumer associations and testing laboratories as well as national and international candle manufacturers' associations have carried out extensive tests in accordance with widely differing measurement methods and evaluation criteria [13-22]. This shows how the theme can be approached from various angles which can in turn, in the worst case, lead to numerous test methods and test criteria being adopted. This poses the danger of over regulating the use of such an everyday item. Avoiding this is in the interest of both the consumer and producer.

The end consumer must be sure that a quality standard for candles is prepared consistently. The most important target of such a quality standard is the protection of the consumer who has the right to purchase high quality products, the proper use of which poses no risk whatsoever for humans or to the environment. The prerequisites for working out a quality standard such as this are the clear definition of the terms categorising the different quality groups as well as determination of quality criteria in order to differentiate the allocation of test and measuring methods and necessary evaluation areas.

All tests, formulations, quality controls and quality agreements connected with quality definitions available to date are summarised in the categories shown in table 1.

Categories of Quality

Technical Parameters	Health-/ Environmental Protection	Safety / Hazard Potential	Pictograms
visible criteria	non-visible criteria	construction-conditioned criteria	criteria relating to handling
candle + combustion	raw materials + combustion products	combustion – possible danger through high flame temperatures –	combustion – handling of open fire –
technical requirements + burning behaviour	purity of raw materials used + harmlessness of combustion products	product development requirements for candle manufacturers	information for consumers about safe handling of the product

Table 1: Structure of a Quality Standard for Candles

4.1 Technical Parameters

These parameters, the so-called visible quality criteria, are technical requirements which the candle as a product has to adhere to e.g.

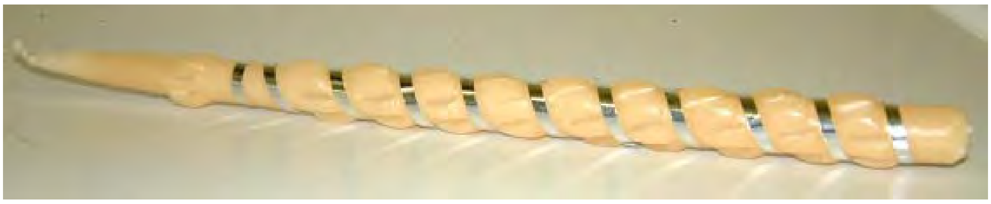
- stability of the candle body
- colour stability
- accordance of information on packaging to reality (e.g. number/quantity, weight or dimension)
- type and durability of design and packaging

This group of quality criteria is second only to the price in influencing the purchasing decision of the customer.

- Mottling,
- Blisters

- Migration

- Heat stability



- Lacking light stability

Figure 16: Visible Quality Criteria

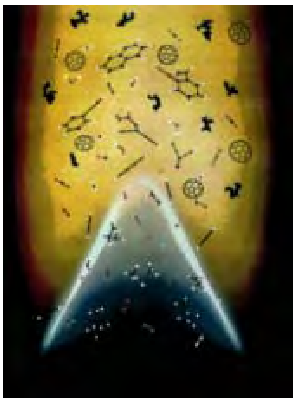
A second group of visible quality criteria is directly related to the burning behaviour of a candle and comprises:

- ➢ the appearance of the flame
- ➢ uniformity of burning
- ➢ the drip-fastness
- ➢ the sooting behaviour
- ➢ the stability and safety performance

As these qualitative properties of a candle are not visible until it is used, they influence future purchasing patterns and thus directly affect the average consumption of candles per customer.

Size of the Flame
Appearance of the Flame

Dripping/Guttering



- Formation of Harmful Substances [23]

Emission of Soot

Figure 17: Quality Criteria for Candles (Burning)

4.2 Health and Environmental Protection

Quality criteria for these requirements are amongst others

- Purity and harmlessness of raw materials used
- Safety, whilst handling as well as during the burning of candles, i.e. no health hazard should be present and no adverse environmental impact may occur.

These quality criteria are still mostly unknown to consumers and not easily accessible. However, the consumer is beginning to find out about them through radio and T.V. programmes, articles in the press and through direct contact with candle manufacturers. Time and again there have been announcements of the consumer being endangered by poor quality raw materials, shortcomings related to technical safety, as well as the formation of harmful substances occurring when the candle does not burn down completely. Providing accurate consumer information as well as the candle manufacturers and associations taking the offensive as far as this subject is concerned, are decisive for consumer protection and the development of the whole candle industry.

4.2.1 Purity and Harmlessness of Raw Materials

Undesirable trace substances, which are occasionally hazardous to health, are drawn to the attention of consumers again and again and trigger discussions about the safety of everyday products (e.g. nitrofen in animal feed; benzene in table water, acrylamide in potato products).

Candles have also been repeatedly focussed upon by critical consumer groups in recent years. Table 2 shows which trace substances have been discussed.

Trace Substance	Year	Reference
Lead	1974	Public Citizen (Consumer Organisation in US) [13]
Heavy metals (e.g. lead); PAH	1987	natur 12/87 [14]
Dioxins (lilac candles)	1992	Consumer Advice Centre Lower Saxony / Environmental Agency Hamburg [15]
Aromatic amines; halogen organic compounds; chromium; copper; polycyclic musk compounds; sulphur	1997	ÖKOTEST 12/97 [16]
Benzene; lead	1999	J.D. Krause, Master's Thesis, University of South Florida [17]
Lead	1999	CPSC (Consumer Product Safety Commission, USA) [18]

Trace Substance	Year	Reference
Nitro musk and polycyclic musk compounds; sulphur; halogen organic compounds	2000	ÖKOTEST 01/2000 [19]
Lead, organic compounds (PCDD/PCDF, PAH, aldehydes, ketones, benzene, isoprene), carbon monoxide, fragrances (musk compounds)	2001	Study of the US Environmental Protection Agency (EPA) [20]
Heavy metals (lead, nickel); organic compounds	2002	Study of the Danish Environmental Ministry [21]
Lead	2003	European Commission; Scientific Committee on Toxicity, Ecotoxicity and the Environment [22]

Table 2: Critical Trace Substances in Candles

In many cases the supposed health hazard emanating from candles has proved to be unsubstantiated, as the trace substances cited could not be proven to exist or were only present in amounts which are not harmful to health [24, 25]. However, a few concerns in a limited number of cases could be proved. These cases only involved additives (colour, fragrances etc.). The responsible candle manufacturers in Europe and USA reacted immediately and banned substances such as lead in wicks from candle manufacturing [26].

The consumer has the right to expect that a candle is safe to use and poses no hazard to health. In addition care should be taken to ensure that not only correct use and handling of the product is guaranteed to be safe, but also use and handling which, although incorrect, could be envisaged e.g. children sucking candles. Thus there is a clear requirement that also oral intake of elements of a candle may not be hazardous to health. This requirement may only be fulfilled by adherence of raw materials and additives to exacting purity criteria.

Requirements, amongst others, are:

- no use of dangerous substances
  (no toxic, irritant, corrosive substances or substances hazardous to the environment)
- use of raw materials of the highest possible purity (removal of undesired trace substances by refining processes)

Paraffin waxes which have been purified by being hydrofinished have been used for years in candle manufacturing. In terms of purity these highest quality paraffin waxes are in compliance with criteria required for food contact applications, for cosmetics as well as for use in pharmaceutical preparations. Highly refined paraffin waxes comply with the stringent quality requirements of *RAL Quality Mark 041 Candles* and guarantee the highest level of consumer protection. Similar purity criteria have been established by the *RAL Quality Mark 041 Candles* for stearin and beeswax as well as for wicks, dyes, lacquers and fragrances.

4.2.2 Combustion Products

When burning candles, as in every case when burning hydrocarbons, water and carbon dioxide are produced. In addition, other combustion products can be formed in traces such as carbon monoxide, nitric oxide, organic hydrocarbons and soot.
As well as the correct relation of the wick to the candle, the purity of the raw materials and additives used plays a decisive role. For example, candle raw materials which have not been adequately refined can contain unsaturated and/or aromatic hydrocarbons which favour the formation of soot. Sulphur in the burning mass of the candle can lead to the release of undesirable sulphur oxides whilst the candle is burning. The use of wicks containing lead can mean that lead compounds can be detected in the air of a room.

Table 3 shows undesirable combustion products, which have been investigated and discussed in connection with burning candles.

Combustion Products	**Year**	**Reference**
Soot	1975	Company Mahr, Aachen: quantitative measurement of soot release from stearic candles [27]
Heavy metal compounds, PAH; aldehydes, ketones	1987	natur 12/87 [14]
Soot; benzene; tetrachloromethane; chloroform; lead; carbon monoxide	1998	California's Proposition 65: 1st case brought against candle manufacturers, traders and retail chains [28]
Soot; benzene; lead	1999	J.D. Krause, Master's Thesis, University of South Florida [17]
Lead	1999	CPSC (Consumer Product Safety Commission, USA [18]
Emission of particulate matter	2001	Z. Guo et al. (US EPA) [29]
Soot, organic substances (PCDD/PCDF, PAH, aldehydes, ketone, benzene, isoprene), carbon monoxide, fragrances (musk derivatives)	2001	Study of the US Environment Protection Agency (EPA) [20]
Heavy metal compounds; organic substances; soot	2002	Study of Danish Environment Agency [21]

Combustion Products	Year	Reference
Soot; formaldehyde; acetaldehyde; PCDD/PCDF; toluene	2002	California's Proposition 65: 2nd case brought against candle manufacturers, traders and retail chains [30]
Lead	2003	European Commission; Scientific Committee on Toxicity, Ecotoxicity and the Environment [22]

Table 3: Undesirable Substances during Candle Burning

In addition to the above listed reports/studies, independent institutes have analysed and evaluated combustion products produced while candles are being burnt [2, 3, 4, 5]. The scientists involved did not need to issue a warning for any of the candles tested. The traces of harmful substances detected do not pose a health hazard for humans, even when candles are burnt frequently. An American report confirmed that burning candles do not pose a health hazard for consumers [31].

Sooting candles are the most obvious sign of bad quality for the consumer. Connected to the visible emission of soot is the concern that harmful substances (aldehydes, PAH) may also be emitted. In the case of high quality candles, which do not visibly emit soot, measurements taken have confirmed that combustion products produced are harmless. The complex theme of soot is to be covered in detail in a separate article.

4.3 Safety / Hazards

As well as technical parameters and parameters for health and environmental protection, safety aspects related to the burning of candles play an important role. Safety requirements connected to candle production e.g. handling waxes, colours and fragrances, glass jars etc. must, of course, be taken into account. The relevant safety data sheets for the products used are available to the producer and potential sources of danger during the working procedure are known and subsequently taken into account.

Without wishing to criticize the atmosphere created by candlelight dinners or the relaxing effect and fascination of warm, golden candlelight the purely technical consideration of each candle shows that the potential of danger exists. From the perspective of consumer safety this is mainly to be seen during burning i.e. based on the open flame with its temperatures of over 1.000 °C. The primary potential danger is thus the possibility of fires starting.

Reports and studies show that in this connection 85 % of all cases of damage occurring may be traced back to incorrect handling of the candle [32], the primary cause is allowing candles to burn unattended (see also point 4.4) [34].

Further to this there are, however, a number of construction related causes which can lead to fires starting i.e. the construction of a candle can decisively influence its burning behaviour.

This is a big responsibility which rests with the candle producer. In the development phase of a candle, the possible safety and danger potential must be recognised, recorded by measurement techniques and monitored. The same applies for candle accessories. Inadequacies in candle holders/sticks, tea light stoves with insufficient air circulation, jars or containers which are not resistant to the temperatures demanded or are made of flammable materials can also be the cause of fires.

For all these important quality criteria connected with the burning of candles there are currently no specific national or international regulations, with the exception of the first incomplete beginnings [33]. In general the European Directive 2001/95/EC of the European Parliament and of the Council of 3 December 2001 on general product safety (Official Journal L 011 of 15.01.2002) applies. This Directive is also the basis for the product safety laws of the member states of the European Union. These regulations see it, in general, as the duty of the producer to only bring products into circulation which are deemed as being safe. This means in particular that hazards and hazardous materials which cannot be recognised by the consumer are to be avoided or at least to be pointed out by the producer. This has had no direct effect for producers up to now as it was generally assumed that the consumer was well aware of the fire hazard and special warnings were, therefore, unnecessary. However, the transition of values which our society is currently undergoing led to it being considered more and more necessary for candle producers to make much more detailed information on the correct handling of candles available. This trend has only just begun and, in Europe at least, candle producers are not yet legally bound to put such warnings on their products.

The candle producer only has direct influence on the use of suitable accessories when they offer them for sale together with their products. Furthermore, it is the duty of national and international candle associations to make their existing experience, and the construction requirements for candle accessories resulting from it, known to the consumer and accessory manufacturers.

It is, however, the direct responsibility of the candle producer to pay attention to safety aspects of their products from the initial development stage on as safety is a subject which is being focussed on more and more in endeavours to establish national and international quality standards.

The main factors which influence candle safety during burning are amongst others:

- Flame size:
  Adjustable by correct selection of the wick. A flame which is too high tends to soot (pollution) and to lead to ignition of combustible materials nearby (e.g. twigs on Christmas trees).

- Temperature of containers’ walls:
  The relation of wick and fuel as well as incorrect positioning and fixing of the wick can cause heating of the side of containers, which can result in burns if touched and/or can ignite materials on which it is standing.

- Formation of a second wick:
  Positioning of flammable materials close to the wick (e.g. dried flowers) as well as falling debris resulting from mushrooming (Figure 18) can initiate the burning of a large area. Furthermore, inappropriate containers e.g. made of permeable pottery, which become saturated with paraffin wax, can act as a second wick.

Figure 18: Formation of Second Wicks Caused by Debris Resulting from Mushrooming

- Temperature of molten paraffin wax:
  Composition of the candle and dimension and position of wick play an important role here. There is potential danger if direct contact with the liquid wax is made. Moreover it is possible to overheat the molten wax ultimately causing a flash or explosion.

- Behaviour when extinguishing:
  Besides the after-glow period the behaviour of the wick during the final burning phase, i.e. just before extinguishing, plays an important role. There is a danger of possible ignition of accessories (e.g. garlands/wreaths of flowers).

➢ Stability during burning:
Thermo-technical instabilities due to candles which are placed too close together are shown in Figure 19. The candle's design can also account for instabilities. Even weight reduction of the candle whilst burning could result in vulnerability to wind in the case of container candles burned outdoors.

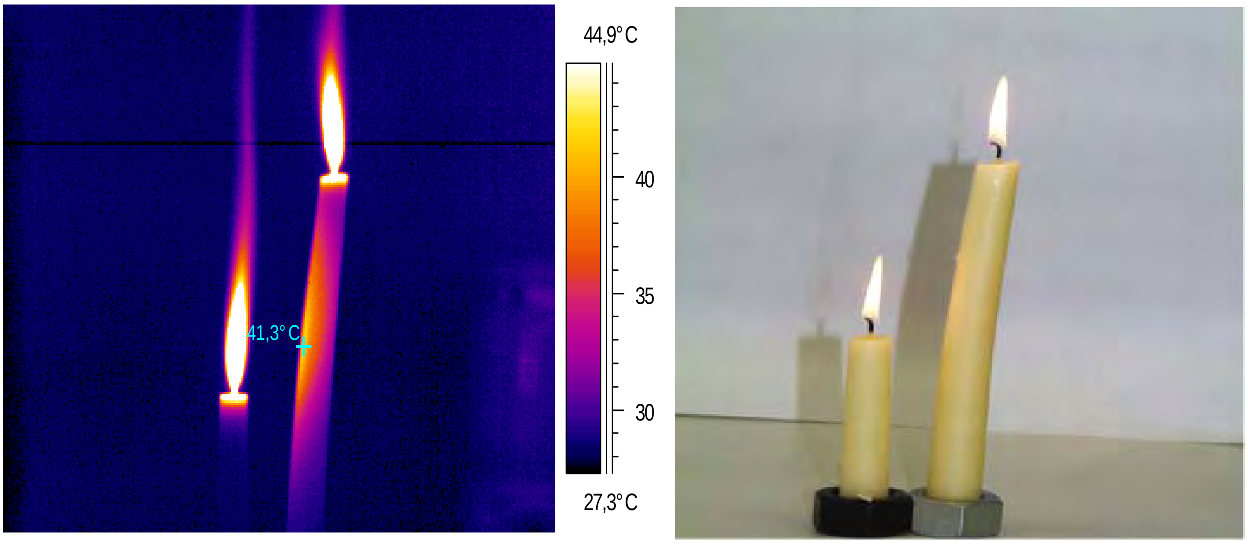


Figure 19: IR-Photo of Candles Burning Side by Side

Producers of raw materials and manufacturers of candles are constantly working on keeping the quality and safety of candles at a high level. These efforts are complemented by specific education of the consumer in the safe use and handling of burning candles.

4.4 Pictograms

Informing the consumer on correct handling of the product is also a significant quality category and an essential part of quality standards. In order to maintain a clear overview this information should be kept to the most important statements, but at the same time offer the consumer information which is easily understood and as extensive as possible.

The candle is often referred to as a living light and the candle's flame is in fact an open fire and should be treated as such. The consumer is also responsible for correct handling of the product (Figure 20).

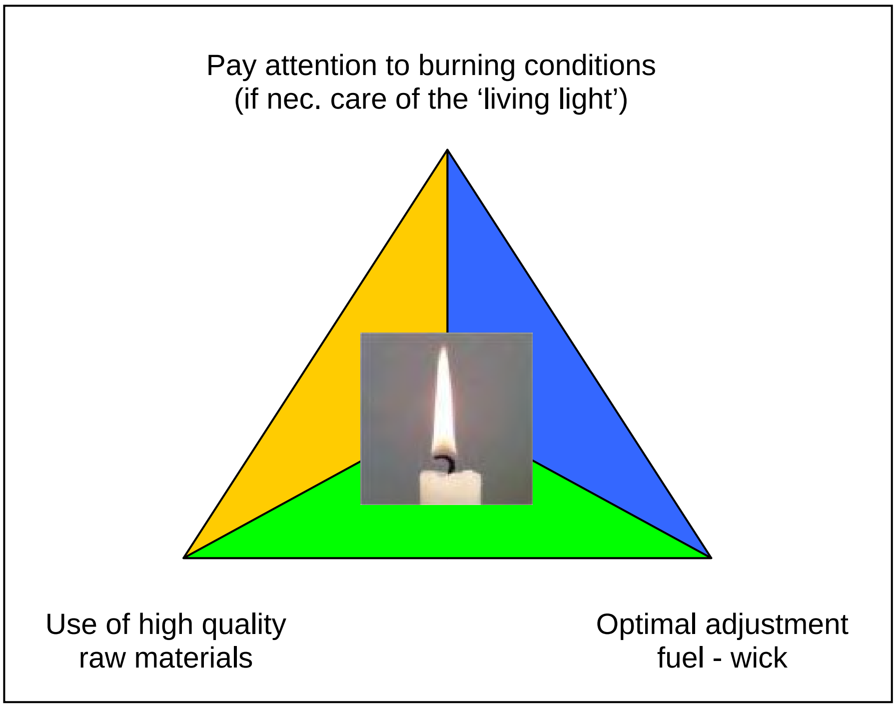


Figure 20: Burning - Influential Factors

The consumers' main need for information is in the sector related to burning behaviour. This includes correct handling of the product whilst it is burning as well as pointing out possible dangers. It is the responsibility of the candle manufacturer to inform the consumer adequately. This takes place most frequently in the form of pictograms which are usually on the packaging.

There are a confusing number of pictograms in/on the market at the moment. Some of them have been developed by retail chains others by national and international candle associations or individual candle producers. The European Candlemakers' Association ordered a survey to be carried out by the University of Utrecht and used the resulting recommendations for the design and choice of pictograms [35, 36, 37, 38].
When observing the multitude of pictograms and indications available today their statements can generally be reduced to the following core messages:

1. Never leave a candle burning unattended.
2. Burn well out of reach of children and pets.
3. Keep well away from flammable items.
4. Observe minimum distance between two burning candles.
5. Only stand on inflammable surfaces – use suitable containers or candleholders.
6. Do not expose the candle to draughts or other air flows e.g. radiators.
7. Keep the burning bowl free of impurities and flammable materials.
8. Extinguish sooting, flickering candles – trim the wick and/or rim before re-igniting.
9. Do not move the candle so long as the wax in the burning bowl is still liquid.
10. Never extinguish burning candles with water.

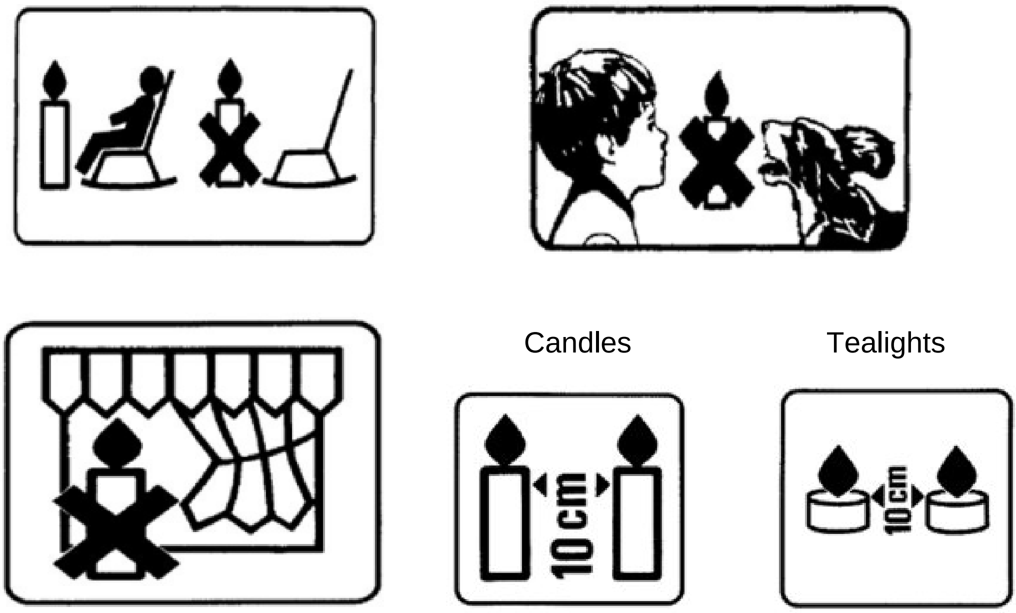


Figure 21: Pictograms

Evaluation of damage caused by burning candles shows clearly that points 1 – 4 are the most frequent causes of such damage. The most important point remains that of never leaving a candle to burn unattended.

5 Summary

The candle is becoming ever more involved in quality discussions in this environmentally aware time we are living in.The prerequisite for soundly based, objective discussions related to the preparation of quality standards is knowledge of the raw materials and additives used. In addition to this clear definition of the terminology and classification pertaining to the candle as well as an understanding of the chemical-physical processes in the burning candle are a must. In addition to the visible quality criteria, the purity of the raw materials and additives used and the fact that all resulting combustion products are harmless play decisive roles.

The most important objective for setting up quality standards for the candle is the protection of the consumer. For this reason the preparation of such quality standards must be approached from the viewpoint of the consumer.

Quality standards for candles can be divided into 4 quality categories:

1. Technical parameters – so called visible criteria – are crucial to purchasing patterns of customers.

2. Purity of raw materials as well as harmlessness of the combustion products formed are, as non visible quality characteristics, important prerequisites for consumer trust in the product.

3. Guaranteed safety – especially when the candle is burning – means the candle shape and design (accessories) must be taken into account in the development phase of new candles.

4.

Consumer information as to the correct handling of the product (e.g. by pictograms), especially related to burning conditions must be targeted and efficient.

General information for consumers is, moreover, an important element of the discussions about the candles quality.

To avoid over-regulation of such an everyday object, national and international candle associations are currently working on the adoption of a uniform European quality standard, whereby existing quality requirements are taken into account. A European quality mark is to be established which will serve the consumer as a clear sign that the product adheres to the requirements of the standard.

Figure 22: Proposed European Quality Mark

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