

**TECHNICAL
REPORT**

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General Issues of Safety in Plastination**ABSTRACT:**

When people intend to start plastination at their institute, they are sometimes unaware of the scope of equipment, auxiliaries and chemicals they need. They may be even less aware of the potential hazards which arise from plastination. Certain chemicals may pose acute or chronic health hazards. Acetone, which is mostly used for dehydration and defatting, is a flammable liquid and therefore brings about fire and explosion hazards.

In this paper, information about the characteristics of some commonly used chemicals in plastination is provided. Suitable personal protective equipment must be used to allow for safe working when handling these substances. For chemicals posing an inhalation hazard, technical room ventilation or workplace ventilation is required to keep the concentration of hazardous vapours below their respective workplace concentration limits. If ventilation is not sufficient, respiratory protection must be worn.

Avoiding the risk of fire and explosion caused by handling of acetone or other flammable liquids is achieved by a combination of measures: Proper laboratory furnishings (ventilation system, electric installations, etc.) are of importance as well as the design of the equipment used for plastination. Depending on the result of the local risk assessment, some appliances like solvent pumps or fans should be designed to be explosion-proof. Organisational protective measures support the technical measures in order to enhance occupational safety. Here, proper instruction of staff is of particular importance..

KEY WORDS: plastination equipment; inhalation hazard; explosion hazard; explosion protection; occupational safety

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Introduction

The technique of plastination, invented by Gunther von Hagens in 1977, offers the opportunity for scientists to produce durable preparations in their own labs (von Hagens et al., 1987). While plastinated specimens as final products are non-hazardous, the handling of solvents and some other specific chemicals during the production process requires (1) awareness of their hazards and (2) some technical, organisational, and personal protective measures to achieve work safety. In the following article, the main potential hazards related to plastination work, as well as recommended measures to effectively avoid explosion and health hazards are discussed.

Important note: work safety is a wide subject where international, national, and regional regulations must be observed. This paper naturally can't cover all regulations,

thus, the following information should be considered as a subjective selection, based on several years' experience in plastination work and on a number of visits to laboratories in different countries, without any claim to be exhaustive.

Hazard types

In plastination, we may be confronted with hazards of the following types:

- Health hazards (acute toxicity, sensitisation, carcinogenicity, etc.)
- Physical hazards (explosion hazard, mechanical hazards, etc.)
- Biohazard (when handling fresh, unfixed specimens)

-Environmental hazard (in case chemicals are accidentally released)

Biohazard and environmental hazard are related to plastination only in a wider context. Biohazard may occur when handling fresh tissue, i.e. before fixation, embalming, or transfer into the dehydration bath. Environmental hazards mainly occur where chemicals hazardous to the environment are accidentally released, and enter the soil or water system. Health and explosion hazards are more closely associated with plastination work, and will therefore be discussed in more detail below.

Gathering information

Information about chemicals presenting health hazards or explosion hazards can be found

- on the product container's label.
- in the Safety Data Sheet (SDS).
 - In Europe, all SDS have a standardised structure of 16 sections according to the regulation no. 1907/2006 ("REACH"; The European Parliament and the Council of the European Union, 2006), and regulation (EU) no. 2015/830 (The European Commission, 2015), respectively. Information about classification and labelling of the product is found in section 2; physical properties are given in section 9.
- in national or international chemicals inventories, e.g. the "Classification and Labelling Inventory of the European Chemicals Agency" which can be found at <https://echa.europa.eu/information-on-chemicals/cl-inventory-database>.

While information about specialised chemicals is usually (and sometimes exclusively) found in the safety data sheets provided by the suppliers, chemical inventories are a good source to review properties of basic substances like solvents.

Minimum information on a chemical product's hazards includes one or more hazard pictograms, hazard statements (in short "H-statements", e.g. H225 "Highly flammable liquid and vapour"), and a signal word ("Warning" or "Danger"). Precautionary statements ("P-statements") indicate measures that should be taken in order to prevent exposure to the chemical (e.g. P284 "In case of inadequate ventilation wear respiratory protection") or to respond to an exposure (e.g. P312 "Call a POISON CENTER or doctor if you feel unwell").

Health hazards

When discussing health hazards, we commonly distinguish three different routes of exposure: skin/eye contact, ingestion, and inhalation. Of these, inhalation is of major importance when working in plastination.

How can we find out if a chemical poses an inhalation hazard? The first approach is having a look at the product label on the container and/or at the SDS. While the hazard pictograms alone are often not very clear in their meaning, the H-statements are more informative. For example, the H-statements indicating acute toxicity through inhalation are very clear. They are, in decreasing severity: H330 "Fatal if inhaled," H331 "Toxic if inhaled," H332 "Harmful if inhaled," and H333 "May be harmful if inhaled". (Note: H333 is included in the United Nations' Globally Harmonized System of Classification and Labelling of Chemicals ["GHS"; United Nations, 2017], Annex 3, but has not been adopted e.g. by the European CLP regulation.)

Besides the H-statements related to acute toxicity, there are numerous others that are, or can be, related to inhalation hazard. Among these are:

-H334 "May cause allergy or asthma symptoms or breathing difficulties if inhaled," indicating the risk of respiratory sensitisation.

-H335 "May cause respiratory irritation," indicating a specific target organ toxicity after single exposure.

-H372 "Causes damage to [state organ] [state route of exposure]," indicating a specific target organ toxicity after repeated exposure. The route of exposure, e.g. "through exposure by inhalation," may be given only if other routes of exposure can be reliably excluded.

Commonly used solvents for dehydration like acetone or isopropanol either have H335 ("May cause respiratory irritation") or H336 ("May cause drowsiness or dizziness"). BIODUR® gas cure S 6 has H332 ("Harmful if inhaled"). H372 applies to all styrene-containing polyester resins that are particularly used for plastination of brain slices, with the wording "Causes damage to hearing organs through prolonged or repeated exposure".

Another approach (besides looking at the H-statements) that can also be of help, is to get an idea about the importance of avoiding inhalation: in the majority of the SDS, very often in section 9, you can find information

about the vapour pressure of the chemical. This value is usually given for a temperature of 20° C, therefore you can easily compare different chemicals. Acetone, for instance, has a vapour pressure of nearly 250 hPa while ethanol's is 58 hPa (Table 1). These values indicate that inhalation hazard has to be taken into consideration. On the other hand, unsurprisingly, for a product like the hardener BIODUR® S3 with a vapour pressure of far less than 1 hPa, inhalation hazard is not of relevance under normal working conditions.

While it is comparably easy to protect one's skin and eyes by wearing suitable safety goggles, protective gloves, arm sleeves, etc., we have to consider several aspects when we strive to avoid inhalation of hazardous vapours. Depending on the chemicals we work with and the scale of the plastination unit, we have to decide which technical and organisational measures are to be taken, alongside the use of personal protective equipment. As the atmosphere holding vapours hazardous to health usually is identical to the one that poses an explosion hazard, technical and organisational protective measures will be discussed below, under the heading "Explosion Hazard".

Personal Protective Equipment (PPE)

Hand/skin protection: protective gloves should be mandatory whenever one works in the plastination lab. Disposable nitrile or latex gloves provide only minor protection against solvents like acetone, though they are most commonly used in laboratories. They are most suited for protecting the hands in situations where there is a risk of minor splashing. Whenever intensive contact with solvent is expected and reliable protection against permeation is required, one should choose a high-quality glove material like butyl rubber (IFA, 2017). When handling larger amounts of chemicals, disposable sleeve protectors and aprons made of polyethylene are a comparatively inexpensive and effective solution (Fig. 1).

Respiratory protection: if technical room ventilation is not available, or is not powerful enough to keep the concentration of hazardous vapours below the locally prescribed limits, protective masks should be worn (Fig. 1). Manufacturers of respirators offer full face masks as well as half-masks. Combination filters, which absorb different kinds of vapours, render the purchase of several filter cartridges superfluous.



Figure 1. Examples of personal protective equipment (PPE) to avoid exposure to chemicals: protective gloves made of butyl rubber (left), disposable apron (middle), full face piece respirator (right).

Physical Hazards

Physical factors leading to a potential hazard can arise, for example when a safety glass plate as part of a plastination kettle bursts, leading to mechanical impact caused by small fragments (Fig. 2). Therefore, it is important to inspect such glass plates from time to time for damage, especially the edges. Damaged glass plates should be replaced with new ones.

Working in cold temperatures carries the risk of cryogenic burns caused by low-temperature impact (Fig. 2). Wearing insulated gloves or chemical protective gloves with cotton gloves underneath avoids this risk.



Figure 2. Physical hazards: when damaged, a safety glass plate shatters into numerous small pieces (left). Working in the cold with unprotected hands bears the risk of cryogenic burns (right).

Explosion Hazard

The most severe hazard in plastination is explosion, caused by the presence of vapour of a flammable liquid in the ambient air at a concentration within its lower and upper explosion limits (Fig. 3). If the temperature is above, or near the flash point (see appendix) of this liquid, any source of ignition able to set free enough energy (inside or in proximity to the air-vapour-mixture) will ignite this hazardous atmosphere, thus causing an explosion. The occurrence of such situations during work procedures

must be identified and considered in a risk assessment. Areas where an explosion hazard may occur should be defined. They are often named “hazard zones”.

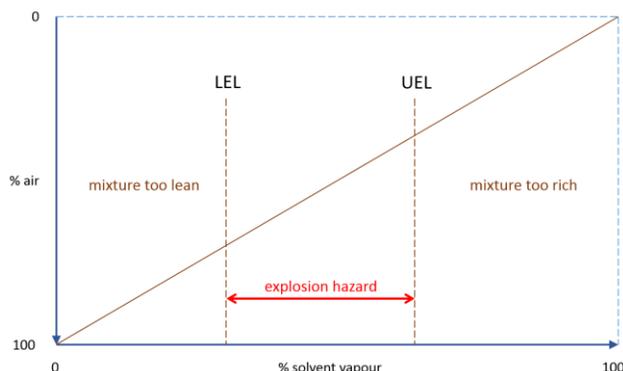


Fig. 3: Potential explosion hazard occurs when the concentration of vapour in the surrounding air ranges between the lower explosion limit (LEL) and the upper explosion limit (UEL).

Measures to improve work safety consist of steps to preferentially avoid the formation of a hazardous air-vapour-mixture, e.g. by effective and reliable removal of the vapour through ventilation. This approach is referred to as “primary explosion protection”. In cases where primary explosion protection is not consistently possible, precautions should be taken so that the hazardous atmosphere will not ignite (“secondary explosion protection”). Secondary explosion protection consists of identifying and eliminating all potential sources of ignition (see below) from the hazard zone.

When working in plastination, we cannot completely exclude the formation of an air-vapour mixture, especially during the dehydration and defatting steps, where acetone or other solvents are used. Some recurring steps involve working at open containers. If we look at the silicone standard method we find that handling of flammable liquids happens during the following activities:

- Storing flammable liquids (mostly acetone)
- Transporting them within your department
- Filling /decanting
- Immersing specimens into or removing them from the dehydration bath
- Taking acetone measurements with a density areometer (“acetonometer”)
- Disposing of acetone

Thus, flammable liquids play a role in numerous steps while working. All of them pose some risk of evaporation. The likelihood of this evaporation, the subsequent

formation of a hazardous atmosphere, and the spatial expansion of this atmosphere, must be considered when determining the explosion hazard in the plastination lab.

Classification of flammable liquids into categories

The hazardous potential of different flammable liquids varies markedly. In the UN “Globally Harmonized System of Classification and Labelling of Chemicals” (GHS; United Nations, 2017), flammable liquids are classified into category 1, 2, or 3, according to their respective flash points and boiling points (Table 2).

Category 1 represents the most severe hazard. It is linked to the H-statement H224 “Extremely flammable liquid and vapour”. If we look at some solvents commonly used in dehydration we find that they all fall into category 2 with H225 “Highly flammable liquid and vapour” (Table 1).

Table 1: Some characteristics of solvents used for dehydration (source: “GESTIS” database of the German Statutory Accident Insurance, 2017)

Characteristic	Ethanol	Acetone	2-Propanol
Boiling point	78 °C	56 °C	82 °C
Flash point	12 °C	< -20 °C	12 °C
Vapour pressure at 20 °C	58 hPa	246 hPa	42.6 hPa
Density at 20 °C	0.79 g/cm ³	0.79 g/cm ³	0.78 g/cm ³
Viscosity (dynamic) at 20 °C	1.2 mPa*s	0.32 mPa*s	2.4 mPa*s
Upper explosion limit (UEL)	27.7 Vol-%	14.3 Vol-%	13.4 Vol-%
Lower explosion limit (LEL)	3.1 Vol-%	2.5 Vol-%	2.0 Vol-%
Partition coefficient n-octanol/water (log POW)	-0.3	-0.24	0.05
Miscibility with water	miscible	miscible	miscible

Some countries like the US have adopted a fourth category of flammable liquids in addition to the GHS: if the flash point of a liquid is higher than 60 °C but does not exceed 93 °C it is classified into category 4 with H227 “Combustible liquid”.

Table 2: Criteria for the classification of flammable liquids as defined by the Globally Harmonized System of Classification and Labelling of Chemicals” (GHS).

Category	Criteria
1	Flash point < 23 °C and initial boiling point ≤ 35 °C
2	Flash point < 23 °C and initial boiling point > 35 °C
3	Flash point ≥ 23 °C and ≤ 60 °C

Determination of explosion hazard zones

In many countries it is mandatory to designate special rooms or areas where people handle flammable liquids as “explosion hazard zones”. An explosion hazard zone is an area where an explosive air-vapour mixture may form with a certain probability and frequency of occurrence. Within Europe, directive 1999/92/EC gives the definition of hazard zones 0, 1, and 2 (Table 3) (The European Parliament and the Council of the European Union, 1999).

Table 3: Explosion hazard zones 0, 1, and 2 caused by gas, vapour or mist, as defined by the European directive 1999/92/EC.

Hazard caused by	Explosion hazard zone 0	Explosion hazard zone 1	Explosion hazard zone 2
Gases, vapours or mists	A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is present continuously or for long periods or frequently.	A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is likely to occur in normal operation occasionally.	A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

Note: explosion hazards not caused by the presence of gas, vapour or mist, but by combustible dust in the air, would lead to a classification into hazard zone 20, 21, or 22. This type of hazard is outside the scope of this article.

Figure 4 gives an example of explosion hazard zone determination. Zone 0 is usually restricted to the interior of conveyor pumps, barrels, and other kinds of receptacles. However, there is no general information on the spatial extent of zones 1 and 2. They must be defined by the person who is responsible on-site.

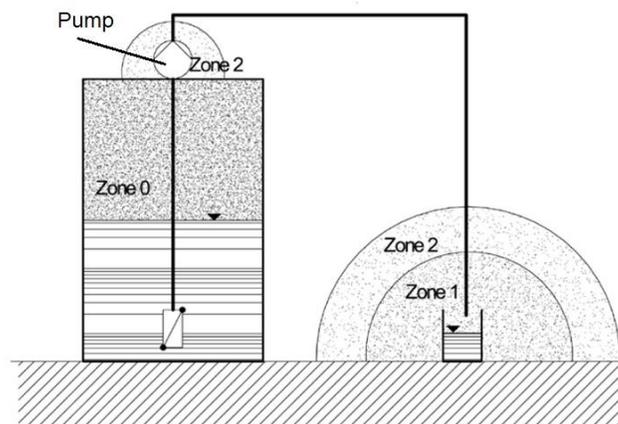


Fig. 4: Example: determination of explosion hazard zones when pumping solvent from a drum into a smaller receptacle. Example drawing given by the German statutory accident insurer VBG (2010)

In the United States and Canada, safety officers in charge of explosion hazard assessment follow either the zone classification system or their traditional definition of hazard class and division, given by the US National Electrical Code (NEC 500) and the Canadian Electrical Code (CEC J18), respectively (Stahl AG, 2016; Siemens AG, 2010). In brief, NEC 500 and CEC J18 define Class I locations as places in which flammable gases or vapours are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures. In class I, division 1 areas, ignitable concentrations of flammable gases, vapours or liquids may exist under normal operating conditions and during repair or maintenance works. In division 2 areas, these ignitable concentrations should not exist under normal operating conditions but only in case of a malfunction, e.g. a container leakage.

Note: Class II refers to explosion hazard caused by combustible dust in the air. Class III refers to explosion hazard caused by easily ignitable fibres.

Potential sources of ignition

If reliable avoidance of a hazardous atmosphere is not always possible, it will be necessary to consider potential ignition sources. In theory, there are many different types, however, not all of them are likely to occur in a plastination laboratory. For instance, the European standard EN

1127-1 lists 13 different types (German Institute for Standardisation, 2011). Among these, flames and hot gases, static electricity, hot surfaces, and electrical equipment are probably of major importance in a typical platination laboratory (nevertheless, all types of ignition sources and the likelihood of their occurrence have to be considered!)

Types of ignition sources (examples)	
Hot surfaces	Electromagnetic waves
Flames and hot gases	Optical radiation
Mechanically produced sparks	Ultrasound
Electrical equipment	Chemical reactions
Transient currents	Lightning strikes
Static electricity	

Flames and hot gases are present for example when using a Bunsen burner.

Static electricity can occur during friction between certain materials, for example when wearing clothes made of synthetic fibre.

Hot surfaces are found in heating cabinets, magnetic stirrers, and similar laboratory apparatus.

Electrical appliances, permanent installations or mobile devices, have to be removed from the explosion hazard zone unless they are manufactured with explosion-proof design (Fig. 5).



Fig. 5: Electrical devices as potential ignition sources (examples): Magnetic stirrer with a heating plate, Computer.

Technical Protective Measures

Technical protective measures should always have priority over other measures. For instance, installation of a workplace ventilation system takes precedence over having the staff wear respirators. The order of priority is

stated in the “T-O-P” principle, according to which, technical measures have priority over organisational measures which, in turn, have priority over personal protective measures.

Effective room ventilation is of major importance when running a platination laboratory. At this point, people are often uncertain about the appropriate air-change rate. The information booklet “Working Safely in Laboratories – Basic Principles and Guidelines” (German Statutory Accident Insurance, 2008) can serve as a reference. Therein, a value of 25 m³ per m² of floor area per hour is given. In other words: the air changes/hour should be approximately 10 (assuming that the ceiling height of the room is approx. 2.5 m). A ventilation system offering two, or several, power levels is recommended, enabling the operator to choose the extraction capacity according to the current need.

If individual ventilation for the laboratory is to be newly installed, one should consider that the vapours of acetone, ethanol, and all other commonly used solvents are heavier than air and therefore will gather near the floor. For this reason, it is advantageous to provide for air extraction openings close to the floor (Fig. 6).



Fig. 6: Room ventilation with a ventilation opening beside a freezer chest. As solvent vapours are heavier than air, it is advantageous to extract them close to ground level.

In some situations, e.g. when working with polyester resin or when preparing epoxy for injecting vessels of organs, workplace ventilation with a flexible extraction arm (Fig. 7) or working under a fume hood is advisable.

A potential equalisation bar should be present in every platination laboratory, in order to provide an earth for

pieces of equipment (Fig. 8). In this way, electrostatic charging can be prevented, and the risk of spark generation will be reduced.



Fig. 7: Extraction arm with explosion-proof fan on top, offering workplace ventilation.



Fig. 8: Wall-mounted potential equalisation bar with several connection options.

Choosing proper explosion-proof equipment

Primary explosion protection, i.e. avoiding the formation of an explosive air-vapour-mixture, is always desirable and has priority. However, as mentioned before, in some steps of the plastination procedure it is necessary to handle flammable liquids in open containers, and therefore we need to apply secondary explosion protection, i.e. avoiding ignition of the explosive atmosphere. This means that all potential sources of ignition are to be removed from the hazard zone. If

removal is not possible, as might be the case for some fixed electrical installations, one should consider their disconnection from the mains, thus achieving permanent inactivation.

For electrical devices that are intended to be operated inside an explosive atmosphere, those with explosion-proof design should be chosen. The suitability of an appliance for use in hazard zone 0, 1, or 2 is shown on the type plate (Table 4) (The European Parliament and the Council of the European Union, 2014):

Table 4: Marking of electrical devices according to directive 2014/34/EU (examples).

Equipment group and category	for use in
 II 1 G	zone 0 or zone 1 or zone 2
 II 2 G	zone 1 or zone 2
 II 3 G	zone 2

The Roman numeral, I or II, indicates the equipment group. For plastination, as well as for general laboratory purposes, only group II comes into consideration. The Arabic numeral, 1, 2, or 3, indicates the equipment category, which determines the hazard zone where it is approved for use.

The capital “G” indicates that the equipment is approved for use in hazardous atmosphere caused by the presence of gas, vapour or mist. See Figure 9 for an example type plate. A capital “D”, on the other hand, would indicate the fitness for use in a hazardous atmosphere cause by the presence of dust.

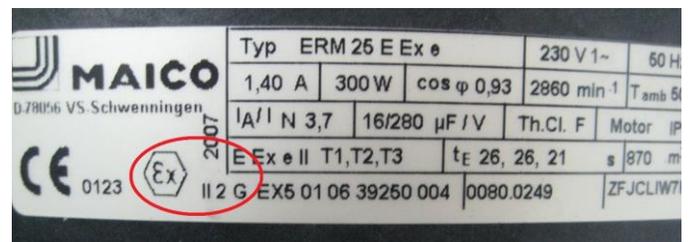


Fig. 9: Example: type plate of an explosion proof fan approved for use in explosion hazard zone 1 or 2.

Organisational Protective Measures

Technical protective measures usually are accompanied by organisational measures to enhance safety, especially when working in a large plastination laboratory.

Organizational measures mainly consist of meaningful labelling, instructions, or restrictions, such as:

- Access restrictions – only authorised personnel are allowed to enter the lab.
- Written and oral working instructions – instruct the staff before they start working in the plastination lab, and then recurrently, e.g. on a yearly basis. Mandatory in many countries.
- -Working alone is not allowed (night time, weekends) – two or more persons are more alert than one, thus avoiding for instance, handling errors. Also enables quick first aid.
- -Regular inspection of equipment for safety – often prescribed at least once-yearly. To be done by a qualified person, e.g. by an electrician.
- -No smoking! Relevant instructions and easily-visible prohibition signs making it clear, even to visitors, that smoking is not allowed in the area (Fig. 10).



Fig. 10: Prohibition signs at the entrance to a solvent storage. The yellow-black warning sign indicates the potential explosion hazard.

Summary

The objective of this article was to review the major types of hazards which may occur when working in plastination, and to create awareness of the precautions that should be taken before starting a plastination laboratory.

Information about the specific hazards of chemicals used in plastination can be obtained from the product labels, from safety data sheets, or from chemical substance databases. Some protective measures for preventing health hazards, such as wearing safety gloves and

protective glasses, are standard and are identical to those required in a normal chemical laboratory. Working underneath an air extraction arm or under a fume hood avoids health hazards caused by inhalation, e.g. when handling solvent-containing epoxy for vessel injection or polyester resin.

The main characteristic of a typical plastination laboratory is the fact that people store, transport, and handle unusual amounts of solvent, mostly acetone. This requires more specific measures in order to prevent (1) health hazards caused by acetone vapour inhalation, and (2) explosion hazards caused by the presence of a vapour-air-mixture. Effective room or workplace ventilation is essential to extract the vapour from the workspace. Despite the ventilation system, however, whenever an explosive atmosphere may form, it is essential to ensure that no sources of ignition are present. Potential sources of ignition include spark-producing electrical installations such as light switches, or portable electrical appliances, for instance stirrers with heating plates, or laptop computers. Electrostatic charging of apparatus may also lead to sparking. This charging can be reliably avoided by earthing the equipment via a potential equalisation bar. In some work steps when you need an electrical appliance inside the explosion hazard zone, you have to use explosion-proof equipment. The suitability of a pump, fan, etc. for operation inside the hazard zone is given on the equipment type plate. All technical protective measures should be accompanied by organisational measures, whereby comprehensive and repeated instructions to staff are of particular importance.

When carrying out a risk assessment for a plastination laboratory one always has to consider the overall situation, including the lab dimensions, the types of chemicals used, their quantities and their physical properties, the capacity of the ventilation system, the number of people who work in the lab (and their level of knowledge), the items of equipment, etc. When estimating the hazard caused by flammable liquids, their respective flash points are the most important characteristic.

As the conditions differ from department to department, and from one lab to the next, there is often no general “right” or “wrong” when people ask, for example, about the suitability of existing premises, or of a certain appliance like a freezer, for plastination. It is necessary to know the overall situation on site, or the specifics of a plastination project before a decision can be made.

It is quite possible to run a plastination lab safely, as proven by a number of labs all over the world where people have worked for decades without any accidents. Everyone who is interested in plastination and is able to provide a suitable surrounding to set up the equipment should feel encouraged to start their own lab. In any case, whether you are a novice or routinely plastinating, it is good to be aware of the hazard situation during all steps of the procedure.

Appendix

A brief explanation of the characteristics of gases or vapours related to explosion protection follows. Values thereof can sometimes be found in safety data sheets, or in some online databases or reference books.

Flash point - the lowest temperature at which a liquid generates flammable vapours above its surface which can be ignited in air by a flame. Examples: acetone: approx. -20° C; ethanol: 12° C; isopropanol: 12° C.

Lower explosion limit (LEL) – a substance-specific concentration of vapour in air. Below the LEL, the quantity of flammable gas in the air is not sufficient to propagate a flame in the surroundings of the ignition source. Practically, the atmosphere will not burn or explode.

Upper explosion limit (UEL) – a substance-specific concentration of vapour in the air. Above the UEL, the concentration of flammable gas or vapour in the air is so high that there is not enough oxygen left to have the reaction of combustion or explosion propagated.

Explosion group – a classification system for gases and vapours, derived from a combination of two substance-specific physical characteristics, “minimum ignition current ratio” and “maximum experimental safe gap”. Describes the “readiness” of a gas or vapour to ignite and the ability of the explosion to pass a narrow gap of given dimensions. Important for the design of certain explosion-proof equipment.

Groups are, in increasing severity: IIA -> IIB -> IIC. Examples: acetone: IIA; ethanol: IIB; isopropanol: IIA (Table 5).

Note: The traditional North American system of classification divides explosive gases, vapours or mists into gas groups A, B, C or D, with A posing the most severe hazard. Group A and B correlate with the international group IIC, group C correlates with IIB, and group D correlates with IIA.

(Auto-)Ignition temperature – a substance-specific temperature at which an explosive air-vapour-atmosphere will ignite, even in the absence of any flame or spark. Examples: acetone: approx. 530 °C, ethanol: approx. 400 °C; isopropanol: 425 °C.

Temperature class – according to their ignition temperatures, gases and vapours are classified into six temperature classes, T1 -> T6, with T6 constituting the lowest temperature range and therefore posing the most severe hazard (Table 5).

Table 5: Explosion groups (IIA -> IIC) and temperature classes (T1 -> T6) of some gases and vapours. Example: The surface temperature of an electrical appliance labelled “T4” must not exceed 135 °C. Temperature subclasses may apply, especially in North America (e.g. T4A).

	T1 Ti > 450 °C	T2 450 ≥ Ti > 300 °C	T3 300 ≥ Ti > 200 °C	T4 200 ≥ Ti > 135 °C	T5 135 ≥ Ti > 100 °C	T6 100 ≥ Ti > 85 °C
IIA	Acetone	Iso-propanol	Gasoline			
IIB		Ethanol Ethylene	BIODUR® S 6	Ethyl ether		
IIC	Hydrogen	Acetylene				Carbon disulphide

Ti = ignition temperature.

References

German Institute for Standardisation (2011): DIN EN 1127-1 Explosive atmospheres – Explosion prevention and protection – Part 1: Basic concepts and methodology; German version. Beuth, Berlin

German Statutory Accident Insurance (2008): Working Safely in Laboratories – Basic Principles and Guidelines. German version. Jedermann-Verlag, Heidelberg.

German Statutory Accident Insurance (2017): "GESTIS" Hazardous Substance Information System <http://www.dguv.de/ifa/gestis/gestis-stoffdatenbank/index.jsp> (in German). Viscosity data taken from various safety data sheets from solvent suppliers.

IFA - Institute For Occupational Safety And Health Of The German Social Accident Insurance (as of 09/29/2017): "Practical solutions for occupational health and safety at company level" <http://www.dguv.de/ifa/praxishilfen/index.jsp>, German version.

Stahl AG (2016): Grundlagen Explosionsschutz ("explosion protection basics," brochure in German) https://r-stahl.com/fileadmin/user_upload/mitarbeiter/PDF/ex-grundlagen-explosionsschutz-rstahl-b-de.pdf (as of 10/13/2017)

Siemens AG (2010): Explosion Protection – Answers for Industry (brochure in German) https://www.automation.siemens.com/salesmaterial-as/brochure/de/brochure_explosion_protection_de.pdf (as of 10/13/2017)

The European Commission (2015): Commission Regulation (EU) 2015/830 of 28 May 2015 amending Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration,

Evaluation, Authorisation and Restriction of Chemicals (REACH).

The European Parliament and the Council of the European Union (2014): "Directive 2014/34/EU of the European Parliament and of the Council on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (recast)," Official Journal of the European Union, L 96, 309 – 356.

The European Parliament and the Council of the European Union (2006): Regulation (EC) No 1907/2006 of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.

The European Parliament and the Council of the European Union (1999): "Directive 1999/92/EC of the European Parliament and of the Council on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres."

United Nations (2017) "Globally Harmonized System of Classification and Labelling of Chemicals (GHS)" Seventh revised edition https://www.unece.org/fileadmin/DAM/trans/danger/publi/ghs/ghs_rev07/English/ST_SG_AC10_30_Rev7e.pdf (as of 10/13/2017)

VBG - Verwaltungs-Berufsgenossenschaft (2010): Broschüre Explosionsschutz – Praxishilfe (brochure in German). VBG, Hamburg.

Von Hagens G, Tiedemann K, Kriz W (1987): The current potential of plastination. Anat Embryol 175:411-421.