

The European UP/VE Resin Association Safe Handling Guide No. 2:

Occupational Exposure to Styrene



When using unsaturated polyester (UP) resins, workers are potentially exposed to evaporating styrene monomer. In all EU Member States, employers are responsible for the control of hazardous substances in the workplace and ensuring that Occupational Exposure Limits (OELs) set by competent national authorities are met. The table in this Guide gives an overview of styrene OELs across Europe. Styrene vapour concentrations are shown in parts per million (ppm) as an 8-hour Time-Weighted Average (TWA), Short-Term Exposure Limit (STEL), or Ceiling (C) limit. The TWA is measured or estimated over an 8-hour working period.

The STEL is the maximum allowable exposure over a short period, usually 15 minutes. Some countries have a Ceiling value that should not be exceeded at any time. Where workplace exposures to styrene may exceed the relevant OEL, appropriate risk management measures must be taken.

In addition to national OELs, the EU REACH regulation (EC 1907/2006) requires registrants of hazardous substances to establish a Derived No Effect Level or DNEL for different populations and routes of exposure.

The DNEL is a threshold for health effects and is used to establish operating conditions and risk management measures that define the safe use of a substance for specific exposure scenarios attached to the supplier's extended safety data (eSDS). The styrene DNEL for long-term worker inhalation exposure is 20 ppm for an 8-hour TWA. The styrene DNEL for short-term worker inhalation exposure is 68 ppm.

Measuring and monitoring emission requirements

A number of European standards outline the requirements for measuring workplace atmospheres and worker exposure to chemical agents like styrene:

EN 838 1996 Workplace atmospheres.

Diffusive samplers for the determination of gases and vapours.

Requirements and test methods.

EN 689 1996 Workplace atmospheres.

Guidance for the assessment of exposure by inhalation to chemical agents for comparison with limit values and measurement strategy.

CEN/TC137

Published standards for assessment of workplace exposure to chemical agents.

Exposure depends on processing techniques

Different application techniques have a marked effect on the amount of styrene evaporating from the resin surface. The rate of styrene evaporation depends on many factors, such as the type of resin, application process, application equipment used, tool design and configuration.

As a guide, the table below (Fig. 1) and Fig 7 (p 9) indicate the typical percentage of styrene loss in the different processing techniques.

Fig. 1	Process	Styrene loss %
	Gelcoat spray	10-14
	Spray-up, non-LSE resin	7-10
	Gelcoat, brush	6-8
	Filament winding	5-7
	Hand Lay-up, non-LSE resin	4-6
	Spray-up, LSE / LSC resin	4-6
	Topcoat, spray	4-5
	Topcoat, brush	3-4
	Hand Lay-up, LSE / LSC resin	3-4
	Pultrusion	1-3
	Polymer concrete etc	1-3
	Continuous lamination	1-2
	SMC/BMC manufacturing	1-2
	SMC/BMC processing	1-2
	Closed processes (RTM/RTM Light/Infusion)	<1

Based on the emission factors described, the usage of resin in the process and the ventilation capacity of the workshop, can be combined to give an indication of the likelihood of the OEL being exceeded.

Fig. 2 Overview of styrene OELs across Europe

Country	8-hour TWA (ppm)	15 min STEL (ppm)
Austria	20	80
Belgium	25	50
Bulgaria	20	50
Croatia	100	250
Czechia	24	90
Denmark	-	25*
Estonia	20	50
Finland	20	100
France	23.3	46.6
Germany	20	40 (4x15 mins)
Greece	100	250
Hungary	50	50*
Ireland	20	40
Italy	10	20
Latvia	2.4	7
Lithuania	20	50
Netherlands	20	20*
Norway	25	37.5
Poland	12	47
Portugal	20	40
REACH DNEL	20	68
Romania	12	35
Slovakia	20	50*
Slovenia	20	80
Spain	20	40
Sweden	10	20
Switzerland	20	40 (4x10 mins)
United Kingdom	100***	250
USA (ACGIH)	10	20

* Ceiling limit

***Obligation to reduce as much as possible

Assessing workplace exposure levels

It is essential that workplace exposures are regularly assessed. Use commercially available equipment for measuring employee exposure and monitoring styrene levels in air. Using such equipment enables FRP moulders to take appropriate measures, where necessary, to reduce exposure and ensure compliance with local or national legislation and relevant exposure scenarios.

Styrene workplace concentrations and ventilation capacity can be estimated as follows: assume an evaporation rate of 1 kg of styrene per hour. In order to stay below a workplace concentration of 20 ppm, approximately 12.000m³ of air is necessary to remove the styrene from the workplace air. Based on the emission factors for the different processes (Fig.1) and the consumption of resin per hour, the necessary ventilation capacity can be estimated.

Wherever closed moulding can be introduced it is well worth the investment. Not only will styrene emissions be substantially reduced (Fig.1) but also the finished products will have greater consistency. Closed moulding techniques include resin transfer moulding (RTM), resin injection (male and female moulds), or resin infusion (flexible film forms the male mould).

An illustration

If we assume that 50 kg of LSE resin is being processed by hand lamination in one hour, this means that the emission of styrene will be around 1.5 kg per hour. A minimum ventilation capacity of 18,000m³ per hour will therefore be necessary to keep the styrene concentration below 20 ppm.

But in practice, the installed ventilation capacity will need to be higher because the styrene vapour will never be homogeneously diluted in the workshop atmosphere.

Typically, for any hand laminating operation, the air in the workroom has to be refreshed between 10 and 15 times per hour. For spray-up operations, this fresh air exchange rate may be considerably higher.

Keeping exposure levels down

There are many ways to keep exposure levels down. Some relate to the proper choice of the raw materials, some to the process or the equipment used, and some to the awareness and the dedication of the worker.

Below we give - without being exhaustive - a number of suggestions to keep exposure levels down. This information should be used in conjunction with the operating conditions and risk management measures specified in any exposure scenarios provided by your supplier.

Cleaner processing

Good housekeeping can have a major impact in keeping styrene exposure down. It also has a very positive impact on safety and operational costs. Use LSE resins wherever possible and always use a resin with the lowest possible styrene content.

Avoid open resin/gelcoat buckets and pails

Resin and gelcoat containers should be stored in a separate well-ventilated room. Avoid overspray and open containers during processing. Any spills should be removed as soon as practically possible.

Keep workshop temperature down

A high workshop temperature will increase styrene evaporation and thus exposures and emissions. Avoid open waste containers and ensure that all remnants of laminates and resin contaminated rags and paper are always put in a closed container. Such containers should be moved outdoors or into a well-ventilated area when the laminating operation is finished.

Although the exposure to styrene takes place mainly through inhalation, excessive skin contact with resins should be avoided, which means always wearing suitable gloves and protective clothing.

Switch to closed mould processing where possible

Use application techniques involving non-atomized dosing of resins, such as roller feeding or use modern spray equipment with fluid impingement nozzles.

Robotized spraying is suitable when series numbers are sufficiently large.



Styrene emission can be substantially reduced by switching to closed moulding techniques like resin infusion (1) or resin injection (2).

Methods for monitoring exposure to styrene



During the processing of unsaturated polyester resins (UP Resins) workers are exposed to styrene emissions. In most European countries, limits are set to determine the maximum level of occupational exposure to styrene. These legal limits are explained.

Exposure to styrene can be measured in several ways, from a simple colour -change tube to a long term data monitoring system.

This Handling Guide gives an overview of the different methods that are available. It will also explain how to choose the best method under different conditions.

Legal requirements for measuring and monitoring styrene

A number of European standards outline the requirements for measuring workplace atmospheres and worker exposure to chemical agents, like styrene:

EN 838 1996

Workplace atmospheres. Diffusive samplers for the determination of gases and vapours. Requirements and test methods.

EN 689 1996

Workplace atmospheres. Guidance for the assessment of exposure by inhalation to chemical agents for comparison with limit values and measurement strategy.

CEN/TC137

Published standards. Assessment of workplace exposure to chemicals.

Most legislation stipulates that the responsibility for measuring and monitoring workplace concentrations of dangerous substances lies with the employer. The company can either carry out the necessary work themselves or they can employ an outside agency to carry out monitoring on their behalf.

The relevance and representative nature of the data generated from workplace monitoring will depend greatly on the quality of sampling. This will be influenced by a great many factors like the process being used; ventilation conditions; time of day; temperature; the position in the moulding cycle at the time of measurement; and the proximity of the measuring device to the operator.

A proper assessment of the real exposure to styrene can therefore only be achieved if the measurements are carried out in combination with a physical observation of the worker who is being monitored.

Measuring systems and parameters

The simplest way to measure a styrene concentration in the air is by using glass tubes that contain a medium that discolours when exposed to styrene.

The extent of discoloration is an indication of the styrene concentration. These tubes are useful for quick spot checks on concentration levels but are no substitute for controlled, accurate, long term monitoring methods.

If styrene exposure is measured to check compliance against legal exposure limits, such as the 8 hr average, equipment must be chosen that can measure the average styrene concentration during the day.

Active carbon badges or Tenax tubes have proven to be a suitable method for this type of measurement.

Active carbon badges alone, however, do not provide information about the variations in exposure due to process conditions, ventilation of the workshop and the position of the worker during the work.

Equipment that records and stores the styrene concentration in an internal memory should be used in that case.

Reading the data and checking the findings against the activities of the worker during the measurement gives valuable information about the relationship between the activities and the exposure level.

When the operators use personal protection equipment, such as breathing masks that provide filtered air, the concentration of styrene in the air will give too high a result in the exposure assessment.

In such cases the exposure should preferably be assessed by biological monitoring: measuring styrene breakdown products in urine samples (mandelic acid (MA) and phenyl glyoxylic acid (PGA) taken from the worker at the end of the shift. The table on next page summarises the most appropriate methods.



Badge monitoring and data analysis system for recording workplace styrene

Measurement methods and instruments

There are a number of different monitoring and analytical test equipment on the market. The following list is not exhaustive and we are not making any recommendations for one company's products or services over another.

Spot measurements

The following companies supply glass tubes with a discolouring medium: Kitagawa (www.komyokk.co.jp) and Dräger (www.draeger.com)

Checks against legal exposure limits

An 8 hour average concentration can be measured by several methods. Much used are active carbon badges, supplied by several companies including 3M (www.3M.com)

Other ways to measure an 8 hour average concentration is by adsorption on Tenax tubes (www.sgab.com).

Styrene monitoring equipment with data acquisition

Several types of portable equipment are available in which measured data can be stored: Photo-Ionisation Detection (PID) is a detection principle with very fast response and a broad measuring range.

PID equipment can be supplied by Rae Systems (www.raesystems.com) or BWTechnologies (www.gasmonitors.com). Other portable equipment is supplied by Draeger (www.draeger.com) (Draeger PAC III).

Infra-Red (IR) analysis or gas chromatography (GC) can also be used, especially in case where more than one volatile gas has to be measured. In most cases this equipment is used for scientific analyses only since it is too expensive for everyday use.

Monitoring method	Kitagawa; Draeger tubes	Carbon; Tenax;	PID PAC III IR	Biological monitoring
Use of method				
Quick estimate	Yes	No	No	No
Check against TLV value	No	Yes	Yes	Yes
Full workday evaluation	No	Yes	Yes	Yes
Real-time operator training	No	No	Yes	No
Process information	No	Yes	Yes	No
Occupational hygiene report	No	Yes	Yes	Yes
In combination with personal protection	No	No	No	Yes
Accuracy	No	Yes (+/- 10%)	Yes	Yes



Combined Photo-Ionisation Detection (PID) and gas monitoring system.

Workplace ventilation in the polyester industry



When using UP resins or other styrenated products, monomeric styrene will evaporate during application, particularly when open-mould processes are being used.

To maintain worker exposure below the TLV limits, proper fabrication lay-out and good housekeeping is important. Application equipment should be chosen which gives reduced styrene evaporation during use.

Whenever possible, always use Low Styrene Emission (LSE) resin or Low Styrene Content (LSC) resins. Good workplace ventilation and suitable personal protection equipment are also essential to minimise exposure levels.

This Handling Guide deals with the principles of workplace ventilation. It also gives information on how to estimate the required ventilation capacity in a polyester workshop.

Ventilation principles

When working with polyester resins, the bulk of the styrene vapour is generated closest to the moulding operation. It should preferably be removed from the air as close as possible to its source. This ensures the most efficient ventilation of the workshop and means that the styrene vapour can be removed at relatively high concentrations with a low air displacement volume.

If the styrene vapour is allowed to diffuse through the workshop, the required ventilation capacity to remove it becomes much higher.

The ventilation system should therefore be designed with this in mind. There is however no standard ventilation blueprint for a polyester workshop, since the volume of resin used and the processing technique are all contributory factors. A strong fluctuation in resin consumption will lead to a strong variation in emission.

The ventilation capacity therefore has to be designed for the maximum emission.

Essentially there are three different methods of ventilation, each with its specific advantages and disadvantages.

General Workshop Ventilation

When applying general workshop ventilation (also called dilution ventilation), the total air volume of the workshop is replaced several times per hour.

This ventilation principle is popular as it is relatively simple and gives a great degree of flexibility in the movement of materials and products in the workshop. The disadvantage is the very high air displacement necessary to keep the styrene concentration at the desired level. In cold periods this may lead to excessive heating costs.

General workshop ventilation is not always sufficient; especially for large mouldings like boats and silos.

In these cases, general workplace ventilation is often supplemented with additional ventilators that blow the air-stream away from the operator. But this inevitably leads to a further dispersion of the styrene vapour throughout the entire workshop.

This is why, when using general ventilation, it is important to keep the air speed as low as possible. This type of ventilation is often achieved by supplying fresh air through textile hoses placed under the ceiling of the workshop (Fig 1).

The styrene-concentrated air is extracted close to the floor level. Only in the case of small moulding operations is general ventilation alone sufficient.

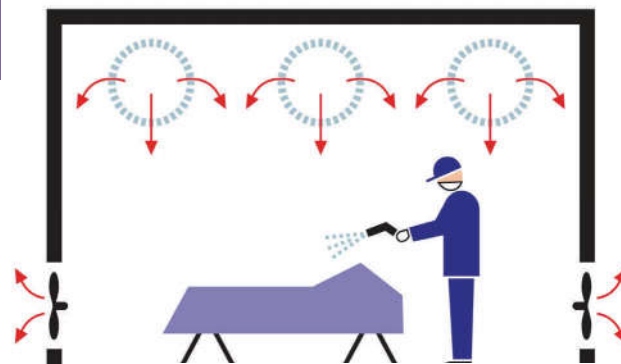


Fig1. Airflow through textile hoses.

Local ventilation

A more efficient method than general workshop ventilation because the styrene vapour is removed through ventilation hoods, installed as close as possible to the place where the styrene is generated. (Fig 2).

Siting the ventilation hoods can be made flexible, so they maintain their efficiency, even when different products are produced. To stay effective, ventilation hoods must be placed as close as possible to the work area. Ventilation hoods can hamper the freedom of movement around the mould, which is a significant disadvantage.

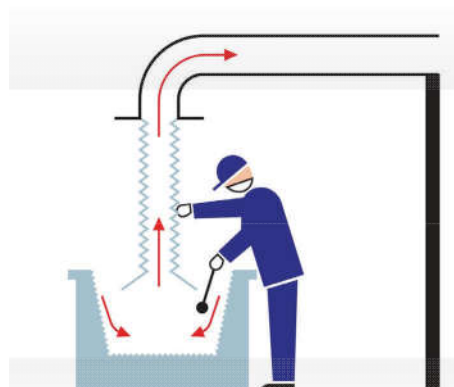


Fig 2. Spot extraction with flexible hose

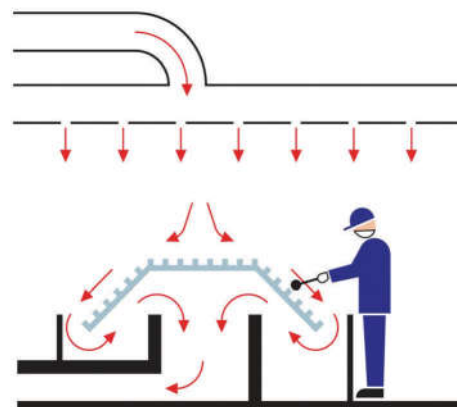


Fig 3. Out-mould induction 'push-pull'.

When ventilation hoods are combined with an array of airstreams that push the styrene-laden air directly to the ventilation hood, a so-called push-pull system results, which can reduce the styrene exposure very effectively.

For small parts laminating tables can be equipped with down draft open pattern tops in combination with semi-enclosed exhaust hoods (Fig 3). A good example of local ventilation is the use of suction channels in the floor of the workplace, combined with a supply of fresh air from above the mould. In this way the operator is always working with his breathing zone in fresh air (Fig 4).

Local ventilation is most effective when relatively small products are made in a fixed place.

Zonal ventilation

Zonal ventilation combines general ventilation with local ventilation. In this case part of the total workshop or compartment is ventilated in such a way that the styrene is removed before it is diluted into the air of the total workshop.

Dividing a workshop into compartments is only effective when there is a good balance between the supply of fresh air to the compartment and the removal of the contaminated air.

Spray booths are a good example of the use of zonal ventilation. A spray booth is a compartment, more or less separated from the rest of the workshop. The air stream can be better controlled and less air is necessary to remove the styrene vapour.

The airspeed in the entrance of a spray-booth should be designed between 0,3 and 1,0 m/s., which may still result in a major air displacement. There are various ways to optimize air displacement in a spray booth.

Fig 6 series shows how the air flow in a spray booth can be optimised. The first sketch (6a) shows that an open spray ex-haust may lead to a lot of turbulence. But if the spray booth is carefully designed to direct airflow to the back of the booth (Fig 6 series b-d), then less turbulence is caused and hence less air is required for the extraction of styrene.

Estimating ventilation requirements

The rate of styrene evaporation in a polyester workshop depends on many variables, such as the type of resin, application process, application equipment used, tool design and configuration etc.

As a guide, figure 7 indicates the typical percentage of styrene loss in different processing techniques, calculated as a loss in the weight of resin.

Booth optimisation set-ups

From this table, the ventilation capacity can be estimated.

A workshop has dimensions 40 x 20 x 5 m, so the volume of the workshop is 8000 m³.

If 150 kg of resin is spray laminated, using an LSE/LSC resin with a styrene evaporation rate of 4 %, then the styrene emission per hour is 6 kgs. Assuming this amount of styrene is spread evenly through the workshop atmosphere, this will lead to a styrene concentration of 750 mg/m³.

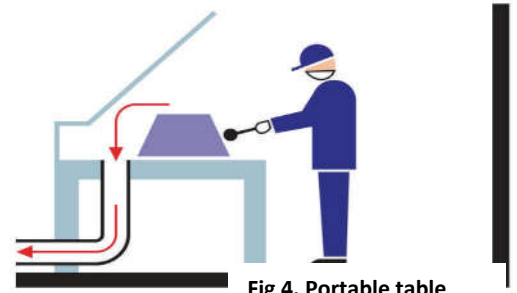


Fig 4. Portable table

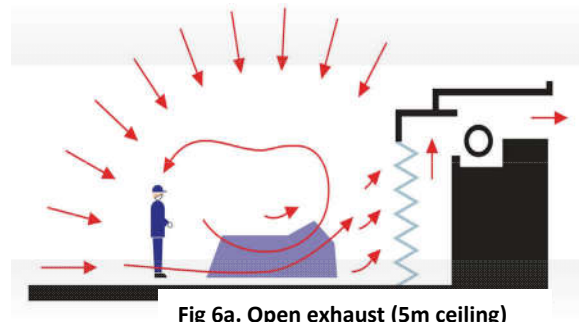


Fig 6a. Open exhaust (5m ceiling)

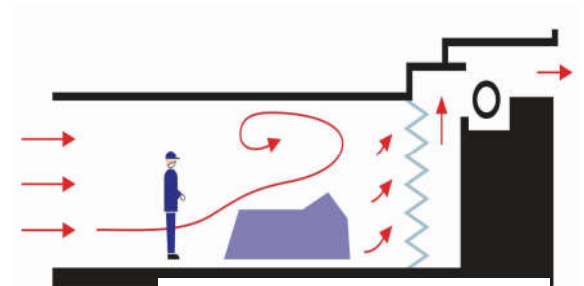


Fig 6b. Booth (5m x 2.5m opening)

Process	Styrene loss (% of resin weight)
Gelcoat Spray	10-14 %
Spray-up, non-LSE resin	7-10 %
Gelcoat, Hand brush	6-8 %
Filament winding	5-7 %
Hand Lay-up, non-LSE resin	4-6 %
Spray-up, LSE/LSC resin	4-6 %
Topcoat, spray	4-5 %
Topcoat, Hand brush	3-4 %
Hand Lay-up, LSE/LSC resin	3-4 %
Pultrusion	1-3 %
Continuous lamination	1-2 %
SMC/BMC Manufacturing	1-2 %
SMC/BMC processing	1-2 %
Closed Processes (RTM/RTM Light/Infusion)	<1%

Fig 7. Styrene loss by process

If dilution ventilation is used, we can estimate the minimum ventilation capacity, required to keep the styrene concentration below the Maximum Allowable concentration (MAC) value. At a MAC value of 108 mg/m³ (25 ppm) the workshop volume has to be refreshed $750 / 108 = 7$ times per hour. This would mean a minimum ventilation capacity of 56000 m³/h.

The real ventilation requirement may be much higher. If the same workshop is also used regularly for gelcoating operations, the emission of styrene is considerably higher so the ventilation capacity must be increased accordingly.

Careful design of the workshop ventilation system can lead to substantial cost savings. **In practice, a properly designed fabrication layout and a ventilation system, optimized for flow and flow directions, will result in a lower ventilation capacity.**

General recommendations

- It is a general misconception that because styrene vapour is heavier than air, it will instantly sink to the floor. Although the density of styrene vapour is 3.6 times the density of air, a styrene concentration of 500 ppm in the air will result in a density increase of just 0.13 %, compared to clean air.
- So slight convection currents and common air movements will already cause the styrene to dissipate throughout the entire workshop.
- Keep the workshop closed. A well-designed ventilation system will only be effective when the air streams are not disturbed by open windows or doors. Opening the doors in summer times to lower the temperature often results in a higher exposure to styrene.
- The inhalation of styrene vapour should be avoided, if necessary by using personal respiratory protection.
- Prevent resins coming into contact with skin and eyes by wearing appropriate safety clothing such as gloves, coveralls and goggles.
- Decant and mix UP resins in a separate well-ventilated room to reduce the likelihood of styrene vapours drifting into adjacent working areas.
- Follow the manufacturers' instructions when mixing and blending additives, accelerators, fillers and peroxides. Being reactive materials, certain additives or combinations of additives can cause unwanted reactions.

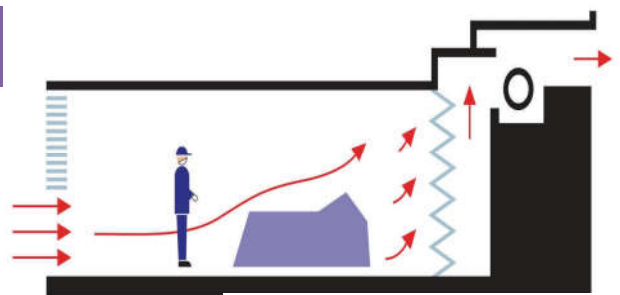


Fig 6c. Booth (5m x 1m opening)

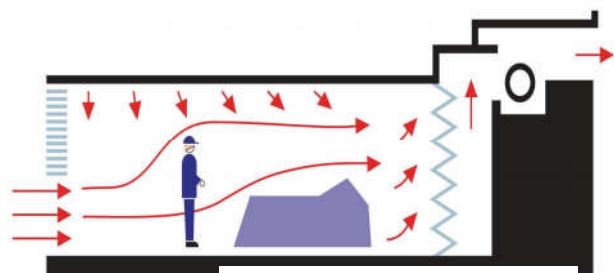


Fig 6d. Booth (air jet support)

Personal protective Equipment



Like many industrial environments, workers in the unsaturated polyester (UP) resin processing industry are exposed to occupational hazards on a daily basis. The use of personal protective equipment (PPE) is the final consideration after process-related measures (e.g. low styrene-emitting resins (LSE), low styrene content (LSC) resins, closed mould techniques) and engineering controls like workplace ventilation have been properly assessed and, where possible, implemented.

To maximise safety at work, it is often necessary to use suitable personal protective equipment.

This guide describes common health risks in the UP resin processing industry and provides general recommendations regarding appropriate PPE. These recommendations should be used in conjunction with company policy and mandatory national legislation on worker protection and safety.

Always refer to the supplier's safety data sheet for more specific information.

Exposure to Volatile Organic Compounds (VOCs)

UP resins are solutions of polyester polymers diluted in reactive monomers such as styrene. Since the polymers are not known to present serious hazards, the most common health risk when handling UP resin is exposure to styrene and other volatile organic compounds (VOCs).

Styrene is a hazardous substance that can be absorbed and distributed throughout the body by inhalation, ingestion, or skin contact. PPE is used when collective protective measures are not sufficient to control exposure to styrene and other VOCs.

The highest risk of exposure occurs during open mould processing of glass fibre-reinforced polyester (GRP) composites. Workplace concentrations of styrene vapour (which can be measured using readily available monitoring devices) may exceed occupational exposure limit values during processes such as hand lay-up, spray-up, and filament winding.

Other chemicals often present in GRP workshops are acetone, vinyl toluene, and methyl methacrylate. When ventilation and work practices prove insufficient, appropriate respiratory protection must be used to reduce exposure to VOCs through inhalation.

Direct, prolonged, or repeated skin contact with UPR or these chemicals can cause defatting, drying, or irritation and must be avoided.

Exposure to organic peroxides

UP resins convert from a liquid state to a solid state when properly catalyzed. Organic peroxides, such as methyl ethyl ketone peroxide (MEKP) and benzoyl peroxide (BPO) are used to cross-link or cure the UP resin. Organic peroxides are aggressive chemicals that can have devastating effects on the eyes and skin.

Any contact with organic peroxides must be avoided by using proper eye and skin protection.

Exposure to dust and mists

Sanding, sawing, grinding, drilling, trimming, machining, and polishing GRP composites and cured UP resin create fine dust that can irritate the eyes, skin, and respiratory system. Spray-up applications may generate resin mists and glass fibres in addition to VOCs.

Proper ventilation is needed when performing these tasks, especially where dusts may contain hazardous flame retardants, pigments, or glass fibres.

PPE is needed if engineering controls cannot adequately reduce the risk of exposure.



Powered air-purifying respirators offer safety and comfort

Exposure to Noise

Continuous or intermittent exposure to noise levels above 80 dBA can cause irreversible hearing loss. In the GRP industry, laminates are often cut with a circular saw or a jig saw. Other noise-hazardous equipment may include the glass fibre cutter on a chopper spray gun and sanding machines.

Noise levels during these activities may exceed exposure limit values and increase risk of hearing loss if proper ear protection is not worn.

Animal studies suggest that inhalation of styrene at high concentrations, especially when combined with noise exposure, can also damage hearing ability.

Particular attention should therefore be paid to a combination of styrene exposure and high noise levels.

In most workplaces, there are other risks not specifically associated with UP resin.

Examples are working on slippery or uneven surfaces, working at heights, or exposure to falling objects.

Personal protective equipment to address these hazards must be separately assessed and is not covered in this guide.

Respiratory protection

Protection against styrene vapour and other airborne contaminants can be achieved using respiratory protective equipment that has been tested and marked according to European standards.

The most common respirators used in the UP resin processing industry are air-purifying respirators equipped with replaceable Type A cartridges for organic vapours. Type A cartridges contain activated carbon and are effective against styrene, vinyl toluene, and methyl methacrylate. Type AX cartridges should be used for low boiling point solvents like acetone.

Activated carbon cartridges have a limited service life depending on factors such as the specific chemical, concentration, use time, breathing rate, relative humidity, temperature, and storage conditions when not in use. Organic vapour cartridges must therefore be replaced at regular intervals to avoid breakthrough.

Type P filters are used for particulates such as resin dust and glass fibres. They should be replaced when breathing becomes difficult. Combination filters for organic vapours and particulates are available as are disposable filtering facepiece respirators for dusts and fibres only.

There is a wide range of respirators and mask styles to choose from depending on how much protection is needed. **Table 1** shows the recommended RPE type for typical UPR use scenarios. A half-mask respirator covers the mouth, nose, and chin. A full face mask covers the mouth, nose, chin, and eyes. Full face masks therefore provide eye and face protection as well as respiratory protection.

It is important to remember that these masks only function properly when there is a tight seal between the face and mask. Beards, moustaches, and sideburns can interfere with proper fit and function of the mask.

Regular fit testing should be conducted to verify the face-to-face piece seal.

Loose-fitting powered air visors or helmets use a battery-operated pump and filter system that the operator wears on his waist.

Air-purifying respirators do not supply oxygen and cannot be used in atmospheres that are immediately life threatening. Positive-pressure air-supplied respirators with emergency escape provisions must be used if there is any potential for an uncontrolled release, low oxygen level, confined space entry, air concentrations are not known, or other circumstances where air-purifying respirators may not provide adequate protection.



Half-mask air-purifying respirator with organic vapour cartridges and particulate filters



Disposable coveralls worn with half face mask and goggles

Choosing the correct Respiratory Protection

Each RPE type and class is categorised by an Assigned Protection Factor (APF). The APF is a numerical rating that indicates how much protection that RPE is capable of providing. For example, RPE with an APF of 10 will reduce the wearer's exposure by at least a factor of 10 if correctly fit-tested and used. The wearer will, theoretically, only breathe-in one-tenth or less of the amount of substance present in the air. With modern equipment, protection efficiency is often much higher.

For protection against styrene vapours, generally an APF 20 or APF 40 filtered/powered respirator should be used, and then only for short-term exposures of <1 hour. For spray-up, hand lamination and other high-exposure activities, an air-supplied hood offering APF of 40 or APF 200 is highly recommended.

APF 40 would imply a 97.5% efficiency as a lower bound (powered masks, combined particulate filter). APF 200 would imply a 99.5% efficiency as a lower bound (hood with constant flow airline).

If there is the potential for aerosol mist to be generated, then a combined organic and particulate filter is required. Particulate filters should meet EN143. P3 types are recommended. Typically, filters should meet at least EN14387:2004.

In general, tight-fitting masks can only be recommended for short periods of use (<1 hour). Heat and sweat can cause discomfort to the operator, leading to the need for readjustment, and this provides opportunities for direct incidental exposures.

Air-fed hoods provide fresh air through a hose from a pump or compressor located in an uncontaminated area. These are recommended where operator activities will exceed 1 hour, for example a worker in a dedicated spray line.

Air fed hood can provide both a high level of protection and operator comfort. Suppliers typically offer hood models that are designed for comfort - they are light and flexible for use with both filters and air line systems, and are thus suitable for long-term wear.

Filters need to be periodically checked and replaced, and this requires a rigid Hygiene regime. A spent filter can lead to inadvertent exposure. Further, the expense of regular filter checking and replacement indicates that installation of an air-supplied system may be the most cost-effective route, whilst offering the highest levels of operator safety and comfort.

Continuous flow (CF) systems are preferable to pressure demand (PD) systems, as they provide less potential for skin drying and subsequent discomfort. Obviously, such systems should be installed with the full cooperation of the affected operators, and specific training in the correct use of PPE for each use scenario is essential.

Dust masks alone provide no protection against vapours and are counter-indicated.

Table 1 shows the recommended RPE type for typical UPR use scenarios.

Eye and face protection



Goggles need to be properly maintained at all times

Safety glasses with side shields protect against flying particles and offer limited eye protection against dust and splashes. Chemical goggles and a faceshield or visor should be worn in situations where there is the potential for direct eye contact with styrene or UP resin, when working with chemicals under pressure, and when handling organic peroxides.

Eye protection can also be obtained by using full face mask respirators. Eye protection should be treated to prevent fogging or designed to allow sufficient air circulation to avoid impaired vision due to condensation.

Operators wearing prescription spectacles must be provided with suitable eye protection that fits over them. Wearers of contact lenses must also use appropriate eye protection in hazardous environments.

All eye and face protection must be properly maintained. Scratched or dirty glasses, goggles, and visors reduce vision, cause glare, and may contribute to accidents.

Emergency eye wash stations

Emergency eyewash facilities must be provided in areas where employees may be exposed to accidental splashes from corrosive materials such as organic peroxides.

These facilities must be visibly marked, regularly checked, and located where they are easily accessible in an emergency.



Hand protection

Suitable chemical-resistant gloves must be worn to protect against skin contact and absorption of chemicals used in the UP resin processing industry. Polyvinyl alcohol (PVA), Viton®, and laminated film gloves are recommended for direct or continuous contact with UP resin.

Gloves made of nitrile rubber or polyvinyl chloride (PVC) may be used for splash protection and brief or intermittent contact with UP resin but are not appropriate for handling acetone, styrene, or methyl methacrylate. Never use natural rubber latex surgical gloves as they are very permeable to chemicals and may cause allergic reactions in sensitive persons.

Gloves should be inspected before each use and removed and replaced immediately if there is any sign of degradation, penetration, or gross contamination. Always wash your hands with soap and water after working with chemicals. Consult the safety data sheet and your PPE supplier for additional instructions on proper glove selection and use. Barrier creams are available to provide secondary skin protection in addition to gloves.



Body Protection

Work clothing should protect against normal contamination and, in particular, resin dust and glass fibres. Whole-body coveralls or other long sleeve work clothing are strongly recommended to prevent skin irritation by glass fibres. Normal work clothing does not protect against direct contact with liquid resins, solvents, and organic peroxides. Clothing or shoes contaminated by harmful liquids must be immediately removed and the skin washed with soap and water to avoid damage.

Hearing protection

Hearing protection devices should be made available during any activity where workers are exposed to noise levels above 80 dBA. Properly fitted individual hearing protectors, banded ear plugs, or earmuffs must be used where noise exposure equals or exceeds 85 dBA.

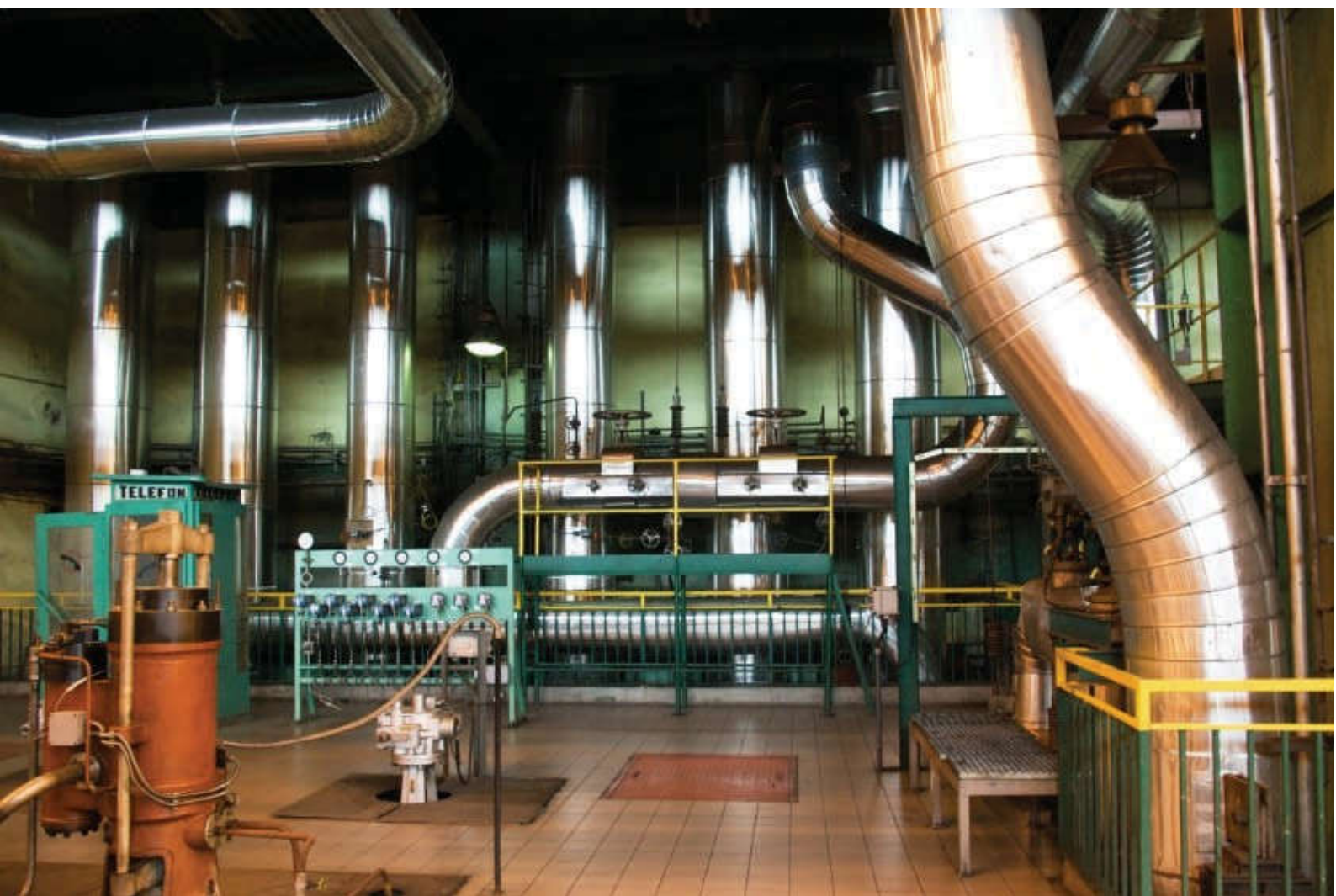
Lightweight earmuffs are available that combine comfort with high levels of noise attenuation (typically a single noise rating or SNR of 25 – 30 dB).



Table 1: Recommended RPE types for activities involving UP Resins

Activity & Duration	Recommended RPE	Diagram
Where short-term intermittent / incidental exposures are possible (waste disposal, equipment maintenance, cleaning) . <15 mins	Reusable half mask respirators – gas/vapour filter (BS EN 140 and BS EN 14387; BS EN 405; BS EN 1827) Filter Type A1 Organic Vapours (BP> 65oC) APF 10	
Short-term low-energy operations (dipping, pouring, brushing) <1 hour	Full face mask respirators – gas/vapour filter (BS EN 136 mask and BS EN 14387 filter) Filter Type A1 Organic Vapours (BP> 65oC) APF 20	
Short-term high energy operations (spraying, brushing) <1 hour	Powered respirators with masks (BS EN 12942) Filter Type A1 Organic Vapours (BP> 65oC) Particulate (P3) filter - aerosols EN143 APF 20- APF 40	
Dedicated low-energy applications (brushing, rolling) > 1 hour > 4 hours	Powered respirators with hoods/helmets (BS EN 12941) Filter Type A1 Organic Vapours (BP> 65oC) APF 20- APF 40	
Dedicated Spray Operations > 1 hour >4 hours	Constant flow airline breathing apparatus with hoods/helmets (BS EN 14594) APF 200	

Styrene abatement techniques



There are a number of abatement techniques available for reducing Volatile Organic Emission (VOCs) into the environment. Some of the techniques are more applicable than others to the treatment of air containing low levels of organic vapours. This is frequently the case when manufacturing fibre reinforced unsaturated polyester resin components using open mould techniques.

This guide describes various processes that can be used to clean exhaust air from polyester processing facilities.

Pollution Prevention

The most effective abatement technique is to prevent the escape of VOC's into the workplace and subsequently into the atmosphere. The use of low styrene emission and low styrene content resins will assist in this respect in open moulding applications. It reduces the level of VOC emitted, compared with conventional resins.

Even more effective are the use of closed mould techniques, such as vacuum bagging, Resin Transfer Moulding (RTM), RTM light (using a light weight, inexpensive male tool) and hot and cold press moulding.

Types of abatement techniques

When styrene emission has to be controlled a number of abatement techniques exist.

Recovery methods

Recovery is only really viable if there is a large amount of solvent that can be recovered and sold, or there is a use for the recovered solvent on the site where it has been recovered. In the GRP industry the exhaust gas contains only low concentrations of VOCs and this increases the capital and running costs of a solvent recovery process; hence there is little economical justification for recovery systems in this industry.

Solvent recovery

- Adsorption recovery, pressure swing or thermal (using zeolites, polymeric adsorbents or activated charcoal)
- Condensation (cryogenic)
- Absorption of oils

Solvent destruction

- On-site oxidation using thermal or catalytic oxidiser (either regenerative or recuperative)
- Bio-filtration or bio-scrubbing
- Adsorption onto a sacrificial bed (activated carbon)
- Absorption into a sacrificial liquid
- Concentration systems followed by oxidation

Abatement techniques where the styrene vapour is removed by incineration or biological processes are more appropriate for the polyester processing industry.

The following processes are used and have proven to be suitable:

Incineration

High temperature incineration or catalytic incineration (at a lower temperature) gives high efficiency of around 99% with energy recycling. To be economically viable the process must use only the combustible pollutant as fuel and require no additional fuel input (except for start up or during short stoppages).

Direct thermal oxidisers

Regenerative thermal oxidisers offer good destruction efficiencies (96-98%) with 90% heat recovery using gravel or ceramic beds.

They can operate auto-thermally, without using extra solvent, at approximately 1g/m³ recovery of solvent. At inlet concentrations below this level additional sources of energy, gas/electricity, are required to keep the oxidiser up to temperature. These oxidisers operate well between 1-5g/m³ and at large air flow-rates and are relatively easy to operate with low capital costs.

Comparative thermal oxidisers use heat exchangers rather than a gravel or ceramic bed to recover the heat, limiting the heat recovery to around 70%.

Hence, more solvent is required in the inlet stream (2-3g/m³) to obtain auto-thermal destruction than with the regenerative oxidiser.

Direct catalytic oxidisers

Catalytic oxidisers have the advantage of lower operating temperatures and greater destruction efficiencies than thermal oxidisers and, hence, lower running costs. However, the cost of the catalyst usually results in higher capital costs. Mini-catalytic systems can be used where the air flow-rates are low or can be used where emissions are intermittent.

Bio-filtration systems

Bio-filtration is the bacterial oxidation of organic matter and results in the conversion of organic matter, like incineration, into carbon based gases and water vapour. Biofilters are good at removing low concentrations of solvent but they suffer the disadvantages of the time taken to destroy VOC's, efficiency of destruction and process control.

Some solvents are easily destroyed by the micro-organisms in the filters but larger molecules, like styrene, need longer residence times for destruction to occur requiring larger systems with greater area. The efficiencies vary from 60-70% for long dwell time bio-filters to 80-90% for buffer effect bio-scrubbers.

Extraction concentrations are limited to 1g/m³ for bio-scrubbers and 0.35g/m³ for bio-filters. Inlet conditions, especially temperature (20 and 40°C), require careful control to ensure the optimum destruction efficiency and to reduce costs. Humidity control is also essential for the survival and metabolism of the micro organisms.

Changes in the solvent inlet concentration affects the metabolism of the micro organisms and will result in low efficiencies at higher inlet solvent concentrations.

Bioway Zerochem system for bacterial oxidation



Adsorption and adsorption onto sacrificial intermediates

These two technologies are similar with the exception of the media and they both suffer from similar disadvantages.

Adsorption usually occurs onto a carbon filter whilst absorption is into a liquid. When saturated with solvent the media are removed and sent off-site for regeneration or disposal.

These systems are not used on continuous or semi-continuous exhaust systems but in areas that are purged intermittently. The running costs are high.

Concentration systems

Concentration systems are probably the best technique for low VOC abatement from exhaust levels typically found in the GRP industry.

There are two types of concentration systems, rotary wheels and fluidised bed. Both remove solvents from the inlet air by adsorption onto zeolites or polymeric adsorbents and desorb them into a hot air stream that is a fraction of the level of the original airflow.

The concentrated air stream contains solvent between 2 and 8 g/m³, which can be destroyed in a catalytic oxidiser with no extra fuel, reducing both capital and operating costs. The selection of a specific concentration system depends upon the concentration ratio required bearing in mind that the objective is to achieve as high a concentration ratio as possible in order to reduce both the capital cost (by decreasing the size of the unit) and the operating cost (by ensuring the system is always auto thermal).

Extra heat generated can be used for reheating the replacement air. The following table gives an overview of the process conditions and approximate investment costs for some of the abovementioned systems.

Technique	Capacity	Ingoing concentration	Outgoing concentration	Investment €/1000Nm ³ /h	Advantages	Disadvantages
Adsorption on active carbon Bio filtration	100-100.000 m ³ /h 50 – 200 m ³ /m ² .h	10-10.000 mgr/m ³ 50 – 500 mgr/m ³	5-100 mgr/m ³ > 10 mgr/m ³	5.000 – 10.000 5.000 – 20.000	- Simple robust technique - Simple construction - Biological process	Saturated sorbent is chemical waste - Large volume installation - Sensitive to poisoning - Inflexible at changing concentrations - Use of additional fuel when not running auto thermal
Catalytic oxidizer	1000 – 30.000 m ³ /h	> 1.000 – 2.000 mgr/m ³	< 20 – 50 mgr/m ³	10.000 – 40.000	- High yield - Relatively compact installation	- Use of additional fuel when not running auto thermal - Emission of CO ₂ and NO _x
Thermal oxidizer	1000 – 30.000 m ³ /h	> 1.000 – 2.000 mgr/m ³	< 20 – 50 mgr/m ³	5.000 – 40.000	- High yield - Relatively compact installation - Heat recovery possible	- Use of additional fuel when not running auto thermal - Emission of CO ₂ and NO _x
Regenerative adsorption Cryocondensation	N.A. 0 – 1000 m ³ /h	500 – 5000 mgr/m ³ 200 – 1.000 gr/m ³	100 – 250 mgr/m ³ 1 – 5 gr/m ³	N.A. 500.000	- No chemical waste - Compact technique - Recovery of VOC's	- Complex installation - Use of liquid nitrogen - Not suitable for wet gas streams

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