Standard Operating Procedure

**Chemical name and concentration:** Hydrogen gas 99.9%

*This is an SOP template. It is not complete until:*

1. *Apparatus design and implementation has been reviewed and approved each of the following:*
   1. *ASU EHS (this includes the ASU Fire Marshall review)*
   2. *ASU FDM-KE (Toxic Gas Team)*
   3. *FSE DO IaST*
2. *Lab specific information is entered into the box below.*
3. *Lab specific engineering controls, apparatus, and procedure are added to the relevant sections.*
4. *SOP has been signed and dated by the PI and relevant lab personnel.*
5. *All italicized/red text has been removed/replaced with information specific to the chemical.*

|  |  |  |  |
| --- | --- | --- | --- |
| **School and department:** | Click here to enter text. | | |
| **SOP preparation date:** | Click here to enter a date. | **SOP approval date:** | Click here to enter a date. |
| **Principal investigator:** | Click here to enter text. | | |
| **Lab manager name:** | Click here to enter text. | | |
| **Laboratory phone:** | Click here to enter text. | **Office phone:** |  |
| **Emergency contact:** | Click here to enter text. | **Contact phone:** | Click here to enter text. |
|  |  |  |  |
| **Laboratory locations covered by this SOP – building and room number** | | | |
| Click here to enter text. | | | |

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| --- | --- | --- | --- | --- | --- | --- |
| **Type of SOP** |  | Process |  | Hazardous chemical |  | Hazardous class |

Hazards Identification

**GHS Classification**

|  |  |
| --- | --- |
| Simple asphyxiant | SIAS |
| Flam. Gas 1 | H220 |
| Press. Gas (Comp.) | H280 |

**GHS Label Information**

**Pictogram**

Logo, icon

Description automatically generated

**Signal Word**

Danger

**Hazard Statement(s)**

|  |
| --- |
| H220 - EXTREMELY FLAMMABLE  GAS H280 - CONTAINS GAS UNDER PRESSURE; MAY EXPLODE IF HEATED OSHA-H01 - MAY DISPLACE OXYGEN AND CAUSE RAPID SUFFOCATION.  CGA-HG04 - MAY FORM EXPLOSIVE MIXTURES WITH AIR  CGA-HG08 - BURNS WITH INVISIBLE FLAME |

**Precautionary Statement(s)**

|  |
| --- |
| P202 - Do not handle until all safety precautions have been read and understood.  P210 - Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking. Heat, Open flames, Sparks, Hot surfaces  P271+P403 - Use and store only outdoors or in a well-ventilated place.  P377 - LEAKING GAS FIRE: Do not extinguish, unless leak can be stopped safely.  P381 - Eliminate all ignition sources if safe to do so.  P304, P340, P313 - IF INHALED: Remove person to fresh air and keep comfortable for  breathing. Get medical advice/attention.  CGA-PG05 - Use a back flow preventive device in the piping.  CGA-PG10 - Use only with equipment rated for cylinder pressure.  CGA-PG12 - Do not open valve until connected to equipment prepared for use.  CGA-PG06 - Close valve after each use and when empty.  CGA-PG02 - Protect from sunlight when ambient temperature exceeds 52°C (125°F). |

**Other Hazards:**

Compressed gas. Burns with invisible flame.

Chemical asphyxiant. Exposure to low concentrations for extended periods may result in dizziness, or unconsciousness, and may lead to death.

Physical and Chemical Properties

|  |  |  |  |
| --- | --- | --- | --- |
| CAS | 1333-74-0 | Melting Point/Range | -259.2 °C (-434.56 °F |
| Molecular Formula | H2 | Boiling Point/Range | -252.9 °C (-422.97 °F) |
| Molecular Weight | 2 g/mol | Flash Point | < -150 °C (< -238 °F) - closed cup |
| Physical State, Color | Gas, colorless gas | Upper flammability/ explosion limit | 77% |
| Odor | Odorless | Lower flammability/ explosion limit | 4% |
| Odor Threshold | No data available | Autoignition Temp. | 566 °C (1051 °F) |
| Evaporation Rate | No data available | Decomposition Temp | No data |

First Aid Procedures

**If inhaled,** move to fresh air and keep at rest in a position comfortable for breathing. If the person is not breathing, give artificial respiration. Avoid mouth to mouth contact. If breathing is difficult, trained personnel should give oxygen. Call 911. Then call EHS at 480-965-1823.

**In case of skin contact,** adverse effects not expected from this product.

Check for aerosol burns (frostbite burns caused by the rapid cooling from adiabatic gas expansion). Remove clothing around the injury and flush affected area for 15 minutes. Call 911. Then call EHS at 480-965-1823.

**In case of eye contact,** immediately flush eyes thoroughly with water for at least 15 minutes. Hold the eyelids open and away from the eyeballs to ensure that all surfaces are flushed thoroughly. Contact an ophthalmologist immediately.

Use nearest emergency eyewash immediately. Call 911. Then call EHS at 480-965-1823.

Ingestion is not considered a potential route of exposure.

Leak and Accident Procedure

**Personal precautions**

* Do not breathe gas. Ensure adequate ventilation.
* If the leak poses a respiratory or explosion threat, evacuate the lab, press the Emergency Shutoff button near the Lab Door, and call EHS (480-965-1823).
* Do not attempt to stop leaks. Contact Lab Manager to determine next steps for any suspected leaks. Shut down gases and exit the Lab.

**Danger:** EXTREMELY FLAMMABLE GAS. Forms explosive mixtures with air and oxidizing agents. Stop flow of product with emergency shut-down button, if safe to do so. Remove all sources of ignition, if safe to do so.

Evacuate personnel to a safe area. Flammable gas may spread from leak. Do not re-enter the area until the emergency response command has communicated it is safe to do so. Work with the Lab Manager to assess the equipment and system installation status including the gas supply lines.

*Include the gas shut-down procedure. Include a photo or schematic of where any buttons/valves required for shutdown are located.*

**Environmental precautions**

Shut off the gas flow, if safe to do so.

Any remaining gas not intended for use should be returned to ASU gas services using their pick-up request process.

**Methods and materials for containment**

* If an aerosol burn injury has occurred or if the lab was evacuated due to unsafe atmosphere, a fellow lab worker shall call 9-1-1, and then EH&S at (480) 965-1823.
* Follow posted ASU Emergency Response Guide procedures for hazardous materials incidents. Do not attempt to fix leaks.
* Wear appropriate PPE if not already being worn.
* Shut off the gas flow at the cylinder by emergency shutdown button.
* Evacuate personnel to a safe area. Flammable gas may spread from leak.
* Do not re-enter the area until the emergency response command has communicated it is safe to do so.
* Repairs on gas systems should only be performed by knowledgeable and qualified personnel.
* Work with the lab manager to assess the equipment and system installation status including the gas supply lines.

Engineering Controls, Apparatus, & Personal Protective Equipment (PPE)

**Engineering Controls**

*If you are using a compressed gas cylinder, and if the cylinder contains 5% or higher H2 gas, a vented gas cabinet is required.*

*Include a labeled diagram, schematic, or photo of the entire apparatus, from the gas cylinder/generator to the external exhaust connection(s). The following attachment is a template that can be edited.*



* *A Restricted Flow Orifice (RFO) is strongly recommended for all flammable and toxic compressed gas cylinders in FSE research labs.*
* *A gas cabinet (a cabinet vented to exterior exhaust) is required for hydrogen gas cylinders with 5% or more hydrogen. FSE strongly recommends having the gas cabinet electrically grounded.*
* *Only clean 316 stainless steel piping can be used for hydrogen gas.*
* *Hydrogen gas is a very small molecule and can pass through the interstitial space of many solids and elastomers. Only use system/apparatus components that are specifically certified and rated for use with hydrogen gas.*
* *Due to small molecule size, the best-performing hydrogen gas fittings are ones that have the most surface-to-surface contact with each other. Fittings with a single point of contact, such as ball-and-cone fittings, can leak easily.*
* ***Never*** *re-use piping or fittings for flammable or toxic gases.*
* *H2 gas flow should be kept linear, with any other introduced gases coming in from side branches. Joints or bends in the piping must be orbitally welded by trained and certified personnel. Contact your lab manager for guidance.*
* *Hydrogen is small enough to pass into the interstitial spaces in the crystalline lattice of steel. This can cause embrittlement of steel and crack propagation. All H2 gas lines must be securely bracketed to structural supports in a way that prevents mechanical stress along the gas lines and fittings.*
* *All metal piping must keep a consistent diameter throughout the apparatus (1/4” diameter is recommended). Large-to-small pipe fittings create mechanical stress.*

*All lines from flammable or toxic gas cylinders/generators must have the following:*

* *Check valve / non-return valve between the gas source and the mixing or use chamber*
* *A bypass valve (3-way ball valve that allows for gas shut-off, and allows for the gas to bypass the use chamber and go directly to exhaust)*

*If gases are mixed, the mixed gas must also have its own check valve and bypass line between the mixing chamber and use chamber.*

*If any parts of the apparatus were purchased, attach or append the manufacturer’s user guide/manual to this SOP.*

*List the maximum flow rate(s) and maximum pressure that the gas system is certified to tolerate.*

*Note the air change rate for the laboratory space where the hydrogen system is located.*

*Before the gas cylinder(s) can be brought to the research lab, all parts of the tool/apparatus & engineering controls, and their design and implementation, must be reviewed and approved by:*

* *The research group PI, collaborating PI, and all researchers working with hydrogen*
* *Your school/department Lab Manager*
* *The FSE DO Infrastructure & Safety Team*
* *The FDM FM KE Facilities Services Team*
* *ASU EHS & ASU Fire Marshall*

**Hydrogen Gas Source**

*This section applies to the gas cabinet where the hydrogen cylinder is stored, or to the hydrogen gas generator (whichever your lab is using).*

Store only where temperature will not exceed 125°F (52°C). Post “No Smoking/No Open Flames” signs in storage and use areas. There must be no sources of ignition. Following appropriate codes and requirements (e.g, NFPA 30, NFPA 55, NFPA 70, and/or NFPA 221 in the U.S.) or according to requirements determined by the Authority Having Jurisdiction (AHJ). Always secure containers upright to keep them from falling or being knocked over. Install valve protection cap, if provided, firmly in place by hand when the container is not in use. Store full and empty containers separately.

*Some gas cabinets have sensors detecting when a gas cylinder is approaching empty. If your lab has this, note what the sensor responds to, and note what actions lab members should take (i.e. ordering a new cylinder and scheduling the change).*

**Other precautions for handling, storage, and use:**

When handling product under pressure, use piping and equipment adequately designed to withstand the pressures to be encountered. Never work on a pressurized system. Use a back flow preventive device in the piping. Gases can cause rapid suffocation because of oxygen deficiency; store and use with adequate ventilation. If a leak occurs, close the container valve and shut down the system in a safe and environmentally correct manner in compliance with all international, federal/national, state/provincial, and local laws. Work with the Lab Manager to evaluate next steps for the leak. Schedule the appropriate repair of the leak with outside contractors or the FDM KE team.

Never place a container where it may become part of an electrical circuit.

All gas cylinders must be strapped securely in place.

**Incompatible materials:** Oxidizing agents. Lithium. Halogens.

Keep away from heat/sparks/open flames/hot surfaces. – No smoking.

Can form explosive mixture with air. May react violently with oxidants.

**Emergency Shut Down**

* *List the steps required to quickly shut down hydrogen gas supply in the event of an emergency.*
* *Include photos of relevant buttons, valves, or other controls.*
* *Clearly label and identify the gas type on each gas line.*
* *Clearly label the emergency shut-off valve with bright red markings.*

**Gas Sensors**

*Hydrogen gas or flammable gas detectors are strongly recommended, directly above the area of use (and any other locations where hydrogen could accumulate), regardless of whether a hydrogen generator or a compressed gas cylinder is used.*

*If a compressed gas cylinder is used, a sensor is required at the storage location.*

For compressed gas cylinders:

Gas sensors should be calibrated to low level alarm at 5% and high level alarm at 10%.

If the sensor registers more than 5%, immediately exit the laboratory. Press the Emergency Gas Shut Off button on the way out, if safe to do so.

10% H2 level detected by the sensor will trigger the general building alarm and force the evacuation of all labs and rooms in the building. In the event of high level alarm, the gas supply is shut down automatically through a pneumatic shutoff.

For hydrogen generators:

Gas sensors should be calibrated to low level alarm at 5% and high level alarm at 10%.

If the sensor registers more than 5%, immediately exit the laboratory. Shut off the hydrogen generator on the way out, if safe to do so.

*Attach or append the gas sensor manufacturer’s user guide/manual here.*

**Gas Sensor Maintenance**

*Include the maintenance schedule.*

*Include the maintenance procedures that are required. If the maintenance must be performed by a technician, include their company contact information.*

*Keep a maintenance log with the lab documentation.*

**Waste Gas Abatement**

Hydrogen gas is flammable and can be ignited by static discharges within exhaust ductwork. If there is any chance that hydrogen gas will enter the building exhaust at concentrations above the LEL/LFL (Lower Explosive Limit / Lower Flammability Limit), then a waste gas abatement device must be used between the release point and the building’s exhaust. Since hydrogen is most easily abated through combustion, this device is often referred to as a burn box.

Gas abatement devices are only designed to handle specific gases. If non-hydrogen gases will be used or generated in the apparatus during the process, check with the gas abatement manufacturer and provide the manufacturer with the highest gas flow rates that might be used. Ensure all gases are compatible with the abatement system, and that gases emitted into the exhaust meet both ASU and national safety & emissions regulations.

*Attach or append the gas abatement manufacturer’s user guide/manual here.*

**Gas Abatement Maintenance**

*Include the maintenance schedule.*

*Include the maintenance procedures that are required. If the maintenance must be performed by a technician, include their company contact information.*

*Keep a maintenance log with the lab documentation.*

**Respiratory protection**

The required engineering controls noted above must provide adequate ventilation to ensure a safe breathing environment.

In the case of leaks, personnel must evacuate from the lab immediately.

Do not re-enter the area until the emergency response command has communicated it is safe to do so.

**Eye, Skin, & Hand protection – During Gas Use**

When compressed gases expand to ambient pressure (adiabatic expansion), they can become cold enough to cause frostbite burns.

* Keep away from the areas of potential leaks.
* Wear appropriate PPE based on other hazards in the lab space.

**Eye, Skin, & Hand protection – During Gas Cylinder Changes**

See the “Cylinder Changes” section below.

*If your lab uses an H2 generator instead of compressed gas cylinders, delete this section.*

Handling Requirements

*If your lab is using a hydrogen generator instead of a gas cylinder, remove references to cylinders below.*

* Keep away from heat, hot surfaces, sparks, open flames, and other ignition sources. No smoking. Use only non-sparking tools. Use only explosion-proof equipment.
* Wear close toed shoes and long pants.
* Protect cylinders from physical damage; do not drag, roll, slide, or drop.
* While moving cylinder, always keep in place removable valve cover. Never attempt to lift a cylinder by its cap; the cap is intended solely to protect the valve.
* When moving cylinders from storage, even for short distances, use a cart (trolley, hand truck, etc.) designed to transport cylinders.
* Never insert an object (e.g, wrench, screwdriver, pry bar) into cylinder cap openings; doing so may damage the valve and cause a leak.
* Never apply flame or localized heat directly to any part of the gas cylinder. High temperatures may damage the cylinder and could cause the pressure relief device to fail prematurely, venting the cylinder contents.
* The lab where the material is being handled must have an approved / certified emergency eyewash and safety shower.
* Ensure you are wearing the required PPE and using appropriate engineering controls as stated above.
* Lab emergency contact information must be readily posted. Easy access to a cellular phone or land line is readily available.
* All lab personnel are required to have completed ASU Compressed Gas Safety training and mentor verification.

Protocol and procedure

*Add your lab’s specific procedures in this section.*

* *Write out separate steps in a bulleted or numbered list format for easy reading.*
* *Please include photos whenever possible.*
* *Be specific and descriptive – future generations of researchers in your lab may need to learn the procedure from this document.*

**Running Experiments**

*Experimental procedure section*

**Purging Lines Before Breaks**

H2 is a very small molecule. When taking a break of 1 week or more between experiment runs, gas supply tanks should be shut off and the lines purged with an inert gas.

*Line purge procedure section*

**Maintenance**

You must keep a tool maintenance log as part of your lab’s documentation.

Include the following columns in your log table, and add columns as needed.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Start date | Start time | Minimum run time | End date | End time | Experimenter’s name | Experimenter’s contact info | Experiment notes |

*Add tool and apparatus maintenance schedule*

*Add tool and apparatus maintenance procedure(s)*

**Important note:** Any deviation from this SOP requires advance PI approval with review of the Lab Manager and FSE DO Infrastructure and Safety Team member.

Cylinder Changes

*If your lab uses an H2 generator instead of compressed gas cylinders, remove this section.*

*FSE Safety strongly recommends scheduling cylinder changes to be performed by the FDM FM KE Facilities Services Team. Safely operating the valves in a gas cabinet requires a working familiarity with the cabinet. Familiarity can turn into forgetfulness if you are performing cylinder changes less than a few times per year.*

Avoid discharge of H2 or exhaust gases to the atmosphere. Do not discharge into any place where it can accumulate above the LEL/LFL (Lower Explosive Limit / Lower Flammability Limit). Waste gas should be flared through a suitable burner with flash back arrestor. Contact supplier if guidance is required.

All gas cabinet cylinder changes will be performed by the trained and knowledgeable personnel of the FDM FM KE Facilities Services Team. (They are trained professionals that work with Toxic and Flammable gases daily.)

* Tear the “full” tab off of the gas cylinder label.
* Schedule the FDM FM KE Facilities Services Team to safely perform the cylinder change at the gas cabinet.
  + Contact Alex Krikliwy ([Alexander.Krikliwy@asu.edu](mailto:Alexander.Krikliwy@asu.edu)) to request the services of the FDM FM KE Facilities Services Team.
* Safely and securely transport the full hydrogen gas cylinder from the gas delivery storage area to the cylinder storage rack next to the gas cabinet. Leave the cylinder cap in place.
* FDM KE Facilities Services Team puts the new cylinder into the gas cabinet.
* With the empty gas cylinder capped, return the cylinder to Gas Services.
* Contact ASU EH&S at (480) 965-1823 with questions.

*If you are*

1. *using hydrogen that is 4% or lower in an inert gas, it is considered non-flammable and a cabinet is no longer required*

*or,*

1. *using hydrogen at a rate such that cylinder changes will be performed every 2-3 months or less, so that a regularly-practiced working familiarity with the gas cabinet valves is maintained,*

*then your research group can opt to demonstrate your level of skill to a lab manager so that your group can perform the cylinder changes.*

The person changing the hydrogen gas cylinder is required to have completed ASU Compressed Gas Safety training and mentor verification.

A lab buddy is required for hydrogen gas cylinder changes. Do not change gas cylinders alone.

The following Personal Protective Equipment (PPE) must be worn before changing the gas cylinder:

* Safety glasses or goggles
* Lab coat
* Long pants
* Closed-toe shoes
* Confirm PPE with KE Toxic Gas Team

*List all steps to your lab’s hydrogen gas cylinder change procedure here, as numbered bullets. Include a photo showing all relevant valves, knobs, and connections involved in the cylinder change.*

Documentation of training

* Prior to conducting any work with this material, Principal Investigator or designee must provide to his or her laboratory personnel specific to the hazards involved in working with this substance, work area decontamination, and emergency procedures.
* The Principal Investigator must provide his/her laboratory personnel with a copy of this SOP and a copy of the Safety Data Sheet or SDS provided by the manufacturer.
* The Principal Investigator must ensure that his/her laboratory personnel have attended appropriate/required laboratory safety training or refresher training within the last one year.
* Lab personnel is responsible for maintaining the training documentation

**I have read and understand the content of this SOP.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Employee name** | **ASU affiliate no.** | **Signature** | **Date** |
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