DEPARTMENT OF AEROSPACE ENGINEERING

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UNIT III - CRYOGENIC ENGINEERING

Cryogenics:

The word cryogenics is derived from a greek word which means, "The production of freezing cold". Cryogenics is the study of the production of very low temperature (below 123 K or 150 °C) and the behavior of materials at those temperatures. It deals with the production, control and application of low temperatures.

Cryogenic Fluids

Liquids with boiling points below minus 130 degrees Fahrenheit are classified as cryogenic. Cryogenic fluids often provide low temperatures for frozen storage, research and experimentation purposes.

A cryogenic substance can fall into one of three groups:

1. **Flammable gases:** Certain cryogenic liquids — such as methane, hydrogen and liquefied natural gas — produce gas that can burn in the air. These are classified as flammable gases.

2. **Inert gases:** Inert or noble gases don't undergo any significant chemical reactions, like burning or combustion, with other substances. Some examples are helium, nitrogen, neon, argon and krypton.

3. **Oxygen:** Many materials classified as "non-combustible" will burn when exposed to liquid oxygen. Organic materials can have an explosive effect in the presence of liquid oxygen. Therefore, there are separate risks and handling precautions to consider with liquid oxygen.

Risks Associated with Cryogenic Substances

The careful and safe handling of cryogenic liquids is crucial. These substances can pose both physical and human health risks, including:

- Pressure buildup
- Embrittlement
- Fire
- Explosion
- Frostbite
- Asphyxiation

Two main hazards are associated with cryogenic substances — very low temperatures and vaporization.

Most metals can withstand extremely cold temperatures. However, materials like plastic, rubber and carbon steel can weaken and fracture when exposed to these conditions. Cryogenic fluids also have cold boil-off vapor that can quickly freeze human tissue. Human contact with cryogenic liquids can cause frostbite, cold burns and potentially severe tissue damage. This makes choosing the appropriate container materials a must.

Additionally, cryogenic fluids release large amounts of gas during vaporization. They can generate dangerously large pressures that could rupture a sealed container. Vaporized liquid oxygen can cause other materials to combust. Vaporized liquid hydrogen is extremely flammable when mixed with air. Additionally, the vaporization of cryogenic substances — excluding oxygen — can cause asphyxiation. Multiple pressure relief devices are typically necessary when working with pressurized cryogenic containers.

Best Practices for Handling Cryogenic Liquids

With the above risks in mind, cryogenic fluids must be properly stored and controlled to prevent any contact with the liquid or its gases. Handle the containers with extreme caution to avoid drops and spills. Never roll them or tip them on their sides.

Cryogenic liquids should be stored in vessels specifically designed for them. These tanks should be double-walled and thoroughly insulated. Remember to keep cryogenic containers and tanks away from walkways, elevators and unprotected platform edges. They also shouldn't be stored in areas where heavy moving objects could strike them.

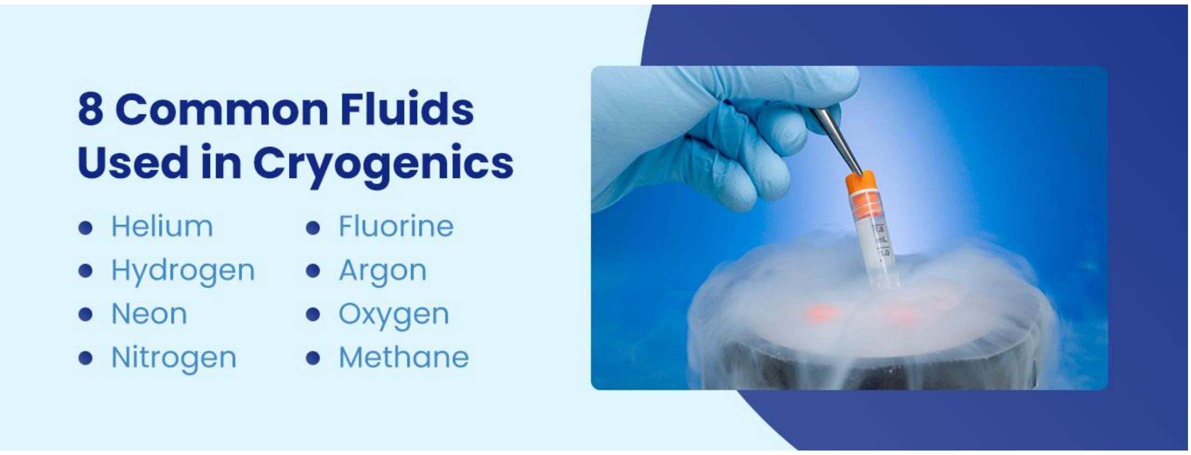
Personal Protective Equipment (PPE)

When filling, transferring, dispensing and handling cryogenic substances, PPE helps protect the skin from cold burns. It also prevents the liquid from splashing into the face and eyes. It's essential to wear the following protective clothing when working with cryogenic fluids:

- Loose-fitting thermal gloves
- Safety goggles
- Face shield
- Lab coat and apron
- Closed-toed shoes
- Long-sleeved shirt and long pants

8 Common Fluids Used in Cryogenics

Here are eight fluids commonly used in cryogenics:



1. Helium

Helium is a colorless and odorless noble gas. It has the lowest boiling point, making it the coldest cryogenic liquid. A temperature as low as minus 269 degrees Celsius is needed to maintain helium's liquid state. Helium is commonly used in the aerospace industry, serving as a pressurizer for ground and flight fluid systems. The automotive industry also uses helium to test critical components.

2. Hydrogen

Hydrogen is a colorless, odorless and flammable gas. It doesn't exist in its pure form on Earth — it must be produced from natural gas (steam reforming) or water (electrolysis).

When in liquid form, hydrogen must be stored at 252.8 degrees Celsius. Liquid hydrogen is an increasingly common renewable fuel and energy generation solution. It's used in various sectors, including space, marine and transportation.

3. Neon

Neon is another prevalent cryogenic refrigerant. This colorless and odorless inert gas has an incredibly high cooling capacity. It has over three times the amount of refrigerating capacity per unit volume than liquid hydrogen. Additionally, it has over 40 times that of liquid helium. Liquid neon has a variety of uses, including:

- High-voltage indicators
- Vacuum tubes
- Lightning arrestors
- Diving equipment
- Television tubes
- Lasers

4. Nitrogen

Liquid nitrogen is one of the most widely used materials used in cryogenics. It's a tasteless, colorless and odorless inert gas with a boiling point of 196 degrees Celsius. Liquid nitrogen can be extracted from ambient air, making it an affordable and relatively eco-friendly substance.

Liquid nitrogen has a multitude of applications, including:

- Shrinking and welding automotive parts
- Testing electronics
- Cooling food and beverage products
- Creating durable, lightweight aeronautics materials
- Freezing and transporting blood, tissue and other biological samples
- Preserving medicines and biological materials

5. Fluorine

Fluorine is a toxic, pale yellow-green gas with a pungent odor. It's highly reactive with other elements, excluding light inert gases. It liquidizes into a bright yellow fluid at 188 degrees Celsius, showing similar transition temperatures to nitrogen and oxygen.

Minor fluorine exposure can irritate the skin, eyes and lungs. Severe exposure can have fatal consequences, complicating breathing and damaging the lungs. Fluorine can be stored as a cryogenic liquid and used to make chemicals, pesticides, dyes, lubricants, ceramics and plastics.

6. Argon

Argon is a colorless, odorless inert gas with a boiling point of minus 185.8 degrees Celsius. Though nontoxic, it's denser than air, making it an asphyxiant in enclosed areas.

While argon is usually stored and transported as a liquid, it's generally used in its gaseous state. It can be used to fill lamps and double-glass panes. It's often used in incandescent light bulbs to prevent oxygen from damaging the filament. Welders can also use argon to protect work areas.

7. Oxygen

Liquid oxygen is a reactive, odorless light blue liquid. It converts to a liquid form at 183 degrees Celsius and serves numerous industries and applications.

For instance, the health care industry often uses liquid oxygen since it streamlines transportation and storage. It occupies considerably less space than gaseous oxygen. Additionally, liquid oxygen is a popular oxidant for liquid fuels in rocket and missile propellant systems.

8. Methane

Methane is a flammable, odorless and colorless gas consisting of hydrogen and carbon. It has a boiling point of minus 162 degrees Celsius and a melting point of minus 182 degrees Celsius. Methane is typically used to manufacture organic chemicals. It can also serve as fuel to produce light and heat.

Cryogenic Material

A cryogenic material is a material at a very low (or 'cryogenic') temperature. This includes liquids and solids such as cardice. Cryogenic liquids are gases at normal temperature and pressure that are liquefied at very low temperatures. Examples include nitrogen, argon and helium. Different cryogens become liquids under different conditions of temperature and pressure, but all have two properties in common: they are extremely cold, and small amounts of liquid can expand into very large volumes of gas.

Direct contact with cryogenic materials can lead to severe cold burns, frostbite and retinal damage if the eye is affected. A leak of cryogenic liquids into a room can lead to a displacement of oxygen − resulting in a potential risk of asphyxiation to occupants.

How to use cryogenic materials safely

1) Ensure risk assessments include an assessment of risk associated with tasks using cryogenic materials.

2) The storage of bulk quantities of cryogenic materials within buildings should be avoided where possible. If considered necessary, this must be justified in the risk assessment and the volumes used minimised.

3) Cryogenic liquids should only be used in well ventilated areas. Decanting of liquid nitrogen shall not take place in small enclosed side rooms off labs.

4) Filling of smaller containers, such as Dewars, from bulk storage vessels to be carried out by trained users only, wearing appropriate PPE: dry thermally insulated gloves and face shield.

5) Users of cryogenic materials should be provided with suitable information, instruction and training in hazards, safe use and movement of Dewars and what to do in an emergency. The training should be recorded and should cover:

- signs of oxygen deficiency symptoms and how to treat a casualty
- what to do if an oxygen depletion alarm sounds
- treating frostbite or cold burns

6) Cryogenic materials should only be stored and used in containers specifically designed for their use. Thermos flasks are not suitable for liquids as they are not designed for the extreme differences in temperature and can fail, leading to a release of the cryogenic liquid.

7) Where the potential for an asphyxiation hazard is identified in the risk assessment, a calculation of the potential oxygen depletion in the area should be made. The outcome of this calculation will determine if further action is required.

If there is the potential for oxygen levels to fall below 21% vol, the following needs to be considered in accordance with the hierarchy of control:

- eliminate hazard − remove cryogenic material from area
- minimise hazard − reduce quantity being used
- engineered control − improve ventilation in area
- administrative control − place oxygen monitor in area with instructions (for levels >19.5% vol only)

Cryogenic Temperature

The cryogenic temperature range is defined as from −238 °F to −460 °F, which is absolute zero, the point where molecular motion is as close to theoretically possible to stopping completely.

Temperatures above −238 °F can, therefore, not be considered cryogenic. Any treatments applied at such temperatures won't qualify as cryogenic treatment. That's because the changes in the metal's crystalline structure that forms the basis of this treatment can't happen unless the metal is treated at cryogenic temperatures.

The development of the field of cryogenics can be traced back to 1877 when oxygen was first cooled to the point that it became a liquid.

One of the most common uses of cryogenic gas liquefaction techniques is the storage and transportation of liquefied natural gas. It's a mixture of ethane, methane, and other combustible gases. When liquefied, it can contract significantly at room temperature and can thus be easily transported in insulated tankers.

What temperatures qualify as cryogenic?

It's not common for us to encounter cryogenic temperatures in normal physical processes. While the freezers at our home are perfectly capable of freezing anything we throw inside them, their lowest temperature is a long way off what can be considered cryogenic.

Specialized equipment and materials need to be utilized in order to reach temperatures that can qualify as cryogenic. These temperatures are easily achieved and maintained with the use of cryogens or liquefied gases. Liquid nitrogen and helium are among the most commonly used cryogens.

The −238 °F to −460 °F is a clearly defined range of cryogenic temperatures. As discussed previously, it's not common to encounter such low temperatures in ordinary processes.

They can only be achieved when using specialized equipment and cryogenic liquids such as liquid nitrogen and helium. However, there are a lot of benefits to be had when treating metals and plastics at cryogenic temperatures.

How do you reach cryogenic temperatures?

It's not possible to reach cryogenic temperatures without the use of specialized equipment and cryogenic gases like liquid nitrogen and liquid helium.

Only then does it become possible to lower the temperature to the range in which processes like cryogenic hardening of metals can be carried out.

Tools

Two main types of tools are used to reach cryogenic temperatures. Cryocoolers and other equipment. This includes cryogenic storage racks and boxes, temperature controllers, cryogenic refrigerators, and tanks.

The cryogenic refrigerators are particularly important as they're used to preserve the cryogenic materials.

In such a refrigerator, the refrigerant is circulated in a fluid flow patch between the first and second chambers. Tanks or dewards are used to store the cryogenic liquids which include liquid oxygen, nitrogen, argon, carbon dioxide, and methane. Large quantities need to be stored.

Liquids

It's impossible to achieve cryogenic temperatures without using cryogenic gases. So what are cryogenic liquids? These are the liquids that have normal boiling points below –130°F.

These are actually some of the most widely used industrial gases that need to be handled, transported, and stored in liquid state at cryogenic temperatures.

Something to be very careful about when handling these liquids is that they can provide very large quantities of gas when they vaporize. A simple example is that of a liter of liquid nitrogen that can vaporize to 694 liters of nitrogen gas at 68°F and 1 atm.

They can't be maintained as a liquid indefinitely, though, even if the containers are properly insulated.

The cryogenic liquids are all extremely cold gases with boiling points below -238°F. The boiling points for liquid nitrogen, helium, hydrogen, argon, and oxygen are -320.4°F, -452.1°F, -423.2°F, -302.5°F and -297.3°F respectively.

Processes

Handling these cryogenic liquids requires extreme care as they can immediately damage skin tissue because of the extremely low temperatures.

As such, a highly specialized process is used when working with these liquids to ensure safety for the workers while achieving the intended objectives.

The gases are used in a cryogenic refrigeration system for the cold station, this can either be a bath of cryogenic liquid or a conductive surface that's cooled to the bath temperature. The materials that need to be processed are then fastened to the surface.

These systems have robust insulation in order to minimize heat leaks into the extremely cooled parts. High-vacuum technology is used in this process and so are cryostats that allow for the temperature to be adjusted by adjusting the rate at which the cold gas vapor removes the heat that flows in from the room temperature.