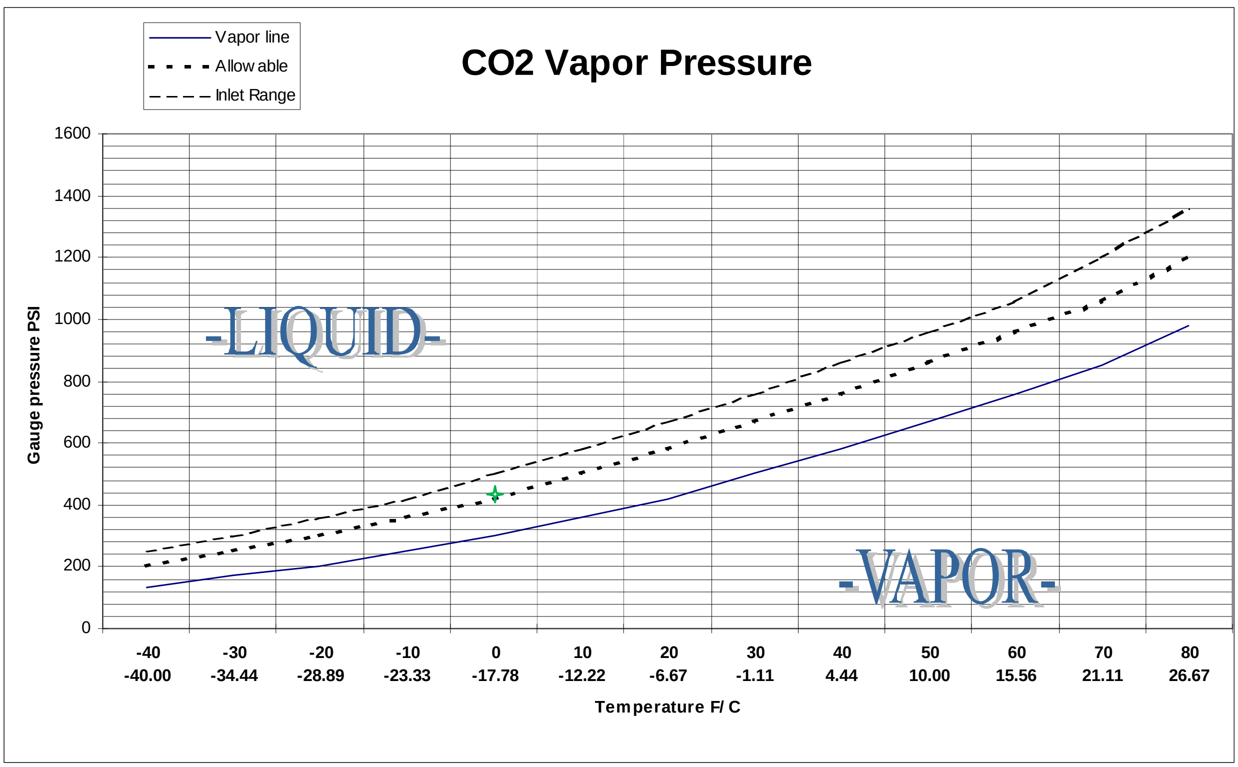
Liquid Carbon Dioxide Design Guide

Introduction:

Carbon dioxide (CO_2) has three states: solid, liquid, and gas. CO2 exists in these states at different temperatures and pressures. For example, CO2 at room temperature and pressure is a gas, where water at room temperature pressure is a liquid. At room temperature CO2 needs to be at 900 psi (62 bar) to keep it in a liquid state.

Below is a vapor curve for CO2 which defines the temperature and pressure when CO2 is either in a vapor state or liquid state. It is essential that the co2 is above the allowable liquid curve for our pumps to pump it. Note that Cat CO2 pumps have a minimum operating temperature of -20 F.

+The green locator on the chart is the inlet condition used for the pump flow calculations in the published literature. 400 PSIG at 0°F



Basic System Considerations

When designing a pumping system, you must have an understanding of the temperature and pressure required to keep CO2 in a liquid state so it can be pumped. At inlet conditions above 88°F (31.1°C) and 1070 psi (74 bar), CO2 is in a supercritical state, meaning it behaves like a liquid, but is compressible like a gas. Our pumps will not pump CO2 at these combined inlet conditions. If the CO2 is too close to its vapor curve when going into the inlet of the pump, the liquid CO2 can easily flash to a gas inside the pump and cause cavitation.

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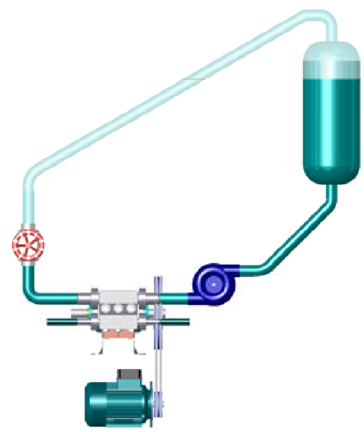
CO2 Inlet Pump Supply:
The liquid CO_2 from the tank is usually very near the vapor line. It is necessary to keep the CO_2 in a liquid state from the tank to the CO_2 pump inlet. This can be done by cooling the CO_2 from the tank while maintaining pressure or boosting the pressure while maintaining temperature from the tank to the CO_2 pump inlet. It does no good to cool the CO_2 if the pressure drops along with it. It will just follow the vapor curve and still cause cavitation.

Un-Swept Volume
Pumping CO_2 is quite different than pumping water. Water is not compressible and has the virtually the same density at inlet pressure to discharge pressure. Liquid CO_2 can change density by up to 15 to 20% when pressure is increased. This means the plunger in the pump will utilize some of its forward stroke to compress the CO_2 in the pumping chamber from inlet pressure to discharge pressure. Once the discharge pressure has been reached, the rest of the stroke will then push the CO_2 out of the pump. This reduces the output capacity of the pump.

The volume of CO_2 between the valves that doesn't get "swept" or pumped by the forward plunger motion is called "un-swept volume." The liquid in the un-swept volume will compress. All pumps will have a swept to un-swept ratio. This ratio must be considered when selecting the flow rate requirement for a system. We recommend you contact Cat Pumps with specific source and discharge conditions for correct pump selection.

Typical System Components (some systems may not need all components):

- CO2 tank
- CO2 Inlet Boost Pump
- Inlet Chiller (not shown)
- Primary CO2 pump
- Needle Valve
- Motor and Optional VFD



CO2 Tank:
CO_2 is stored in a special tank designed to contain the CO_2 in a liquid/gas state at a certain temperature and pressure, typically at 0°F and 300 psi (20 bar). The bottom of the tank is liquid and the top is gas. A special vent on the top of the tank releases gas to cool it and keep it in this condition. The tank is plumbed from the bottom of the tank where the CO_2 remains liquid. The tank is similar to a pot of boiling water.

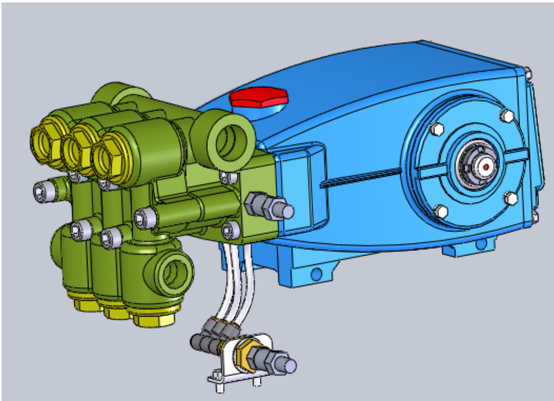
CO2 Chiller:
A refrigeration unit can be used on the inlet lines going to the pump for the rated flow and heat exchange required. The unit should remove enough heat to lower the temperature such that the CO_2 is in the liquid state at its given inlet pressure. Well insulated lines and pump head are also recommended. **The seals in the Cat Pump will operate down to -20°F. Running too cold will cause the pump seals to become stiffer and fail prematurely. Do not pump the CO2 below -20F.**

CO2 Boost Pump:
As shown above, a low pressure transfer pump can also be used to raise the pressure of the CO2 to keep it liquid between the tank and CO2 pump inlet. The booster pump plumbing is connected so the flow passes through the primary CO2 pump manifold back to the top of the tank. This booster pump should be able to handle CO2 right at the vapor line. Rotary vane pumps are typically successful in handling it. Check with your supplier for suitable pumps. A needle valve is installed on the return to create back pressure on the CO2 to keep it liquid. The boost pressure is typically around 50-100 psi (7 bar) above tank pressure. Less pressure is required if the lines are insulated.

Primary CO2 Pump:
The primary pump uses a special manifold using inlet seals to handle the cold CO2 liquid. Special drive end components are also used in the pump to handle the higher inlet pressures. Special valve retainers are also used, preventing condensation and ice build-up behind the low pressure seals and on the plunger rods, which is critical to seal longevity. Ice build-up on the plunger and rods can quickly destroy a seal.

Venting:

- A special low pressure seal is used that has an ability to run without liquid.
- The vent ports are plumbed with a check valve to let any CO2 that has migrated by the high pressure seals to vent out of the pump, while preventing air and moisture from entering the manifold chamber.
- Special seal retainers with a check valve also prevent air and moisture from contacting the moving plunger rods and barrier slingers.



CO_2 pump with special vented system and check valves attached.

Valve:

- A suitable valve will be required to create back-pressure in the co2 line back to tank so that pressure will build in the inlet when the booster pump is turned on.

Motor and Optional VFD

- A suitable motor and drive package will be required to operate the pump. Since most pumps have a maximum speed of 450 rpm when pumping CO2, a large reduction ratio is usually needed to get motor shaft speeds down to pump shaft speeds. VFD's are frequently used to slow down the motors as well as belt drives and gearmotors for reduction.

System Start-up and Operation:

1. Turn on the booster pumps
2. Turn the needle/ball valve in the feed supply loop to increase the inlet pressure to a suitable pressure given your inlet temperature for liquid state CO2, (see vapor curve). Allow CO2 to cool primary pump head.
3. Verify the temperature and pressure by reading the inlet pressure gauge at the primary CO2 pump inlet.
4. Turn on the primary CO2 pump and adjust for the application requirements. Frost will appear on the outside of the manifold due to condensation freezing.