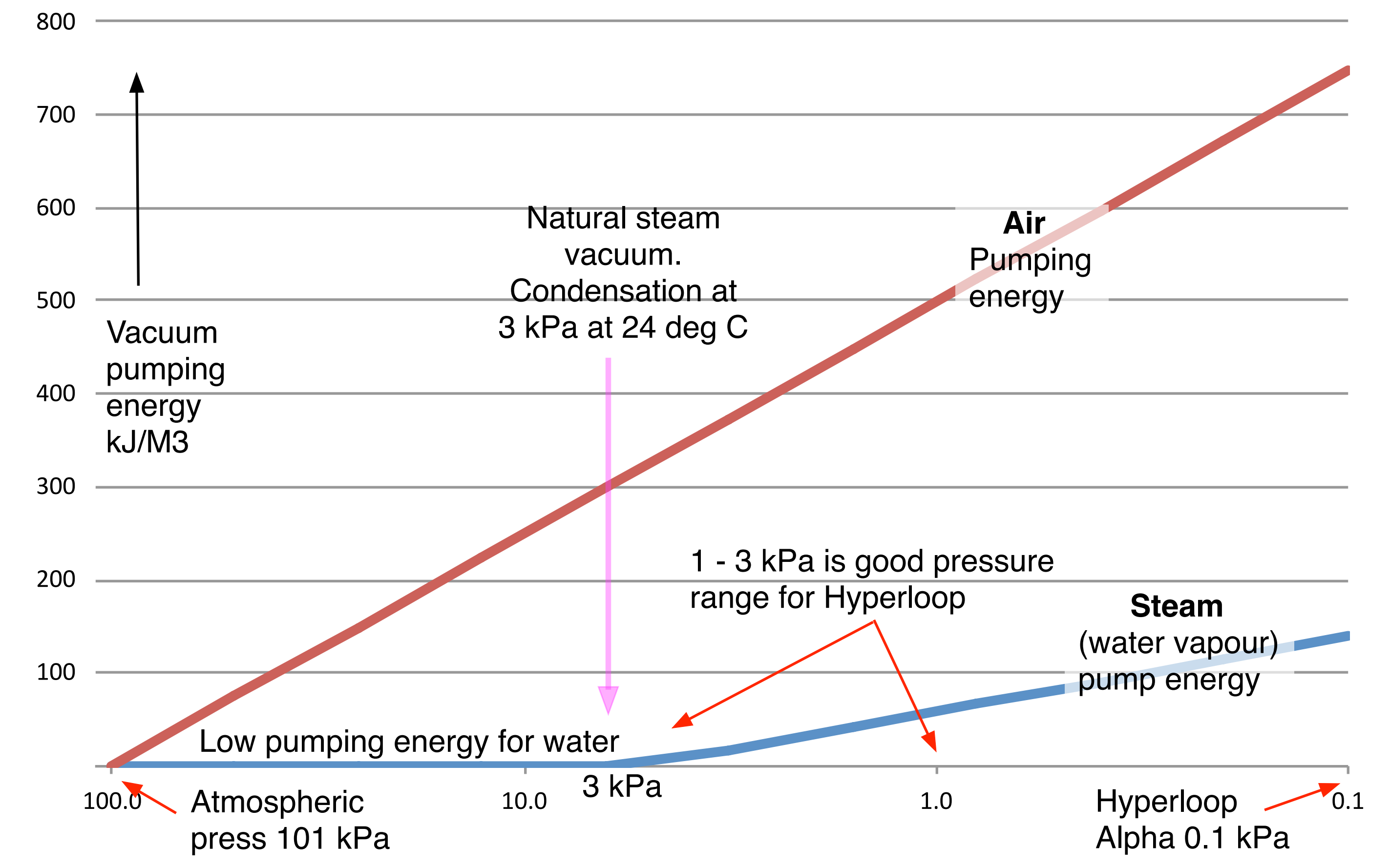
Low energy vacuum pumping using steam

*A note about vacuum units, we always refer to **absolute pressures** in the tube. The fundamental SI unit is Pascals Pa, or the more convenient kPa. Atmospheric pressure is 101 kPa. Millibars are good, 1kPa = 10 mB. The vacuum industry uses relative units like inches of mercury, or the absolute mm of mercury Torr. What they call a 'high vacuum' is actually a low absolute pressure.*

Hyperloop runs in a near-vacuum, to reduce air resistance and reduce the problems of flow in the tube when travelling around the speed of sound. Alpha's proposed tube pressure is 1/1000th of an atmosphere, 1 mBar, or 0.1 kPa.

But Hyperloop needs to balance performance, against the challenges and costs of achieving it. The feasibility of the "world's largest vacuum tank" has been questioned by vacuum engineers, particularly at the low pressure as proposed in Alpha.



The chart above compares the vacuum pumping energy for a tube containing air or steam (water vapour). The difference with steam is that it **condenses naturally** at a low pressure at ambient temperatures.

Pumping energy is proportional to Volume times Pressure change. At a pressure of 3kPa, 30 mBar, 1 Kg of air has a volume of 26 cu M. The vacuum pump expends a lot of energy to pump this up to atmospheric pressure of 101 kPa, 1000mBar. With steam at this pressure, in contact with the tube wall or a condenser below 24ºC, the steam condenses to water. The 1kg of water now only occupies 1Lt of volume which needs to be pumped. The pumping energy is now 26,000 times less than for air.

We may want to operate at a tube pressure below the condensing pressure, so we need to pump the steam up to the 3-5 kPa in the condensers. At 1 kPa the vacuum pumping energy for steam is about 7 times lower, because we only need to pump up to 3-5 kPa, whereas air needs to be pumped up to 101 kPa. At Alpha's proposed pressure of 0.1 kPa, steam requires about half the pumping energy of air.

The triple benefit of using steam in the tube

- ***Greatly reduced vacuum pumping energy.***
- ***Cooling problems of the pod are solved.***
- ***Increased speed of sound, reduces shockwaves and drag.***

Natural Steam Vacuum

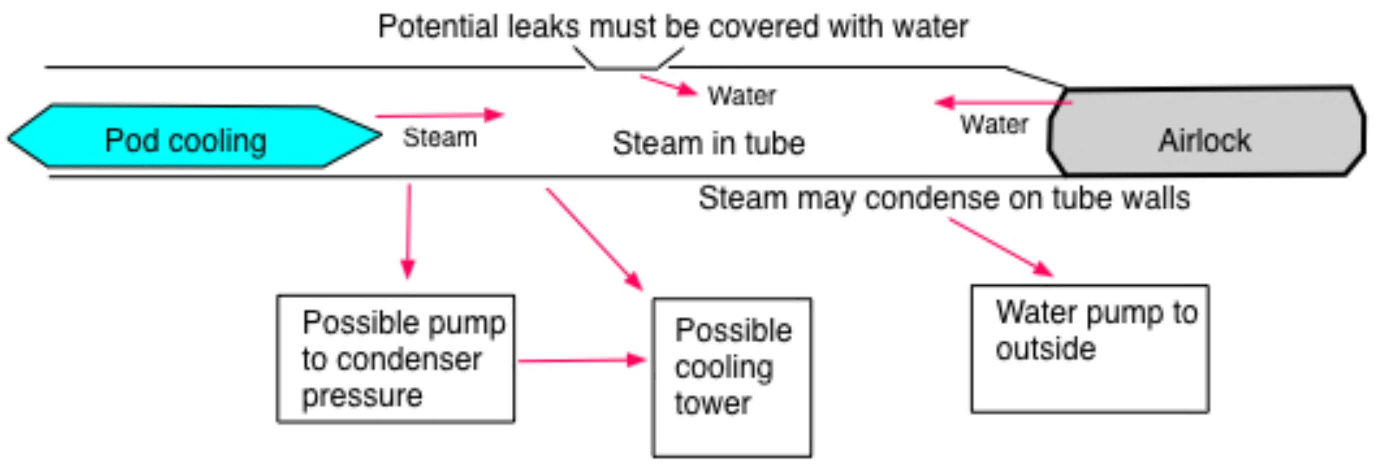
A Natural Steam Vacuum is formed when a vessel full of steam (water vapour) cools down to room temperature. This is used for preserving fruit, and the can-crushing trick where water is boiled in a can, which is then sealed and cooled.

If we are content to run Hyperloop at 3 kPa, 30 mBar, the vacuum is easy to maintain, and consumes very little power. Later we will see how we can reduce the tube pressure down to 1 kPa, 10 mBar with a little extra energy.

The boiling point of water, and the condensing temperature of steam varies with pressure. At atmospheric pressure, steam condenses below 100ºC. At room temperatures, this pressure is much lower, and is a convenient way to produce a vacuum.

- At 25ºC steam condenses at 3.1 kPa, 31 mBar
- At 13ºC steam condenses at 1.5 kPa, 15 mBar
- At 7ºC steam condenses at 1.0 kPa, 10 mBar

At 3 kPa, any steam that enters the tube will condense naturally on the walls of the tube, provided that it is below 25ºC. There is no vacuum pumping, and the energy of pumping out the condensed water is minimal.



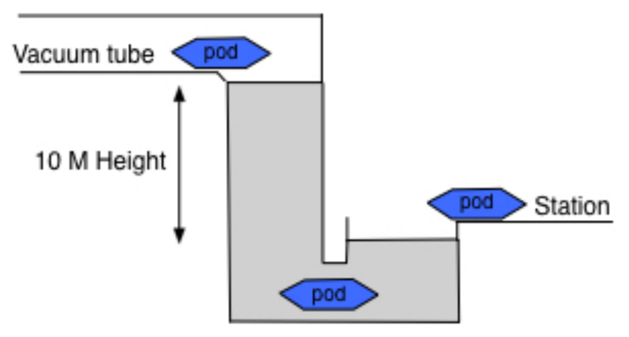
The diagram above shows the places where water or steam can enter the tube, it all needs to be pumped out. It is important that no air enters the system, as it needs to be pumped right up to atmospheric pressure. With a natural steam vacuum, the only pumping energy is for the water. For lower pressures, some steam pumping is required up to condenser pressure.

Airlocks, water flushing

We need to eliminate the ways in which air can enter the tube, because it increases the pressure, and needs to be pumped out at atmospheric pressure. The airlocks could be vacuum-pumped to remove the air, the air would need to be pumped to a low pressure, this would take a long time and consume energy.

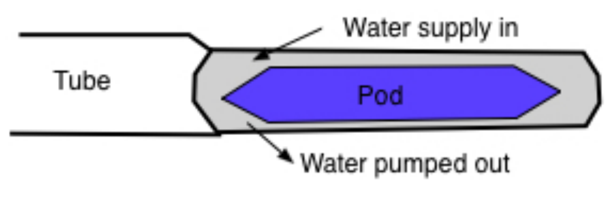
This shows a clever airlock, patented decades ago. It proposed water to seal the tube, with a height difference of 10 m between tube and station, so the water column supports the vacuum.

The pod is immersed in the water, and carried up to the tube with no power required. A pure vacuum is not possible in the tube, only a natural steam vacuum of about 3 kPa, depending on temperature.



Water flushing is an excellent way to move the air from the airlock, it requires low energy, and could save pumping time.

This diagram shows a water-flushed airlock. The air in the airlock is displaced as the water is pumped in. Then the water is pumped out to make a steam vacuum. It requires very little energy to pump the water, as the water does not expand in a vacuum, whereas air expands many times when is is pumped. This airlock could operate quickly, with a turnaround less than 60 seconds.



The only disadvantage is that the pod needs to be waterproofed. The passenger cabin, electronics and other sensitive equipment need to sealed anyway, as they cannot operate in a vacuum.

Lower pressures than a natural vacuum

We may want to run at a lower pressure that the 3kPa, 25ºC natural steam vacuum. We can lower it a little, by condensing the steam at a lower temperature. If the whole tube is chilled to 13C, the pressure halves to 1.5 kPa. At 7ºC it reduces to 1 kPa. We can also do this by having external condensers, that are chilled.

The other way to achieve lower pressures, is by pumping the steam to an external condenser. If we want to run at, 1 kPa, we need to pump the steam up to 3 kPa to condense in a 25ºC condenser. The power for this is quite low.

If we want to run at the 0.1 kPa as proposed in Alpha, we still have a good energy saving by having steam in the tube. We only need to pump it up to 3 kPa for condensing, rather than 100 kPa if it was air.

Air removal

Leaks are a big problem with any vacuum system. We need to make sure that any leaks are for water, not air. For example, there needs to be a manhole every km or so for emergency exits, and leaks are possible. If we cover the seals with water, no air will leak in. Any flow of water will indicate the leak.

Power stations use steam, and they all have condensers to provide the vacuum to make the turbines more efficient. But every system will suffer from some air leaks. So when the steam is condensed, the remaining pressure is always a little higher due to the air which does not condense.

So all condensers have a vacuum pump, which pumps the non-condensible air or other vapours up to atmospheric pressure for removal. Provided the amount of air leakage into the system is small, the power for this is not significant.