Active cooling and level measuring of liquid oxygen aboard submarines

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When designing and constructing military grade submarines one is faced with a number of challenges that are more or less unheard of in any other industry. One of those challenges is how one is supposed to store the large amount of oxygen needed for combustion based underwater propulsion. Another is how one is supposed to integrate a level sensor that will be inaccessible for 30 years inside the vacuum insolated steel pressure vessels that are surrounded by an almost impenetrable layer of security measurements and safety features.

The problem arises on the behalf of the cryogenic nature of oxygen. In its liquid phase the temperature of the oxygen needs to be kept under about -180 degrees Celsius which leads to a quite enormous temperature deference against the surrounding. This in turn means that a significant amount of heat will be transferred to the oxygen and sequentially a temperature rise and thermal expansion of the liquid will take place, slowly increasing the pressure in the confined space where the liquid is kept. This pressure rise is managed by dumping some of the oxygen when a given pressure is reached, effectively lowering the stored oxygen-mass and pressure in the tanks.

This is, to put it lightly, not an elegant solution. Not only will the oxygen supply dwindle over time but one also risks giving away the submarines location. Some if not even much of the submarines flexibility is also lost due to the increased time dependency. What's more is the reduced underwater endurance on the behalf of the dumping and the reduced fill rate used so to leave room for the thermal expansion inside the tank.

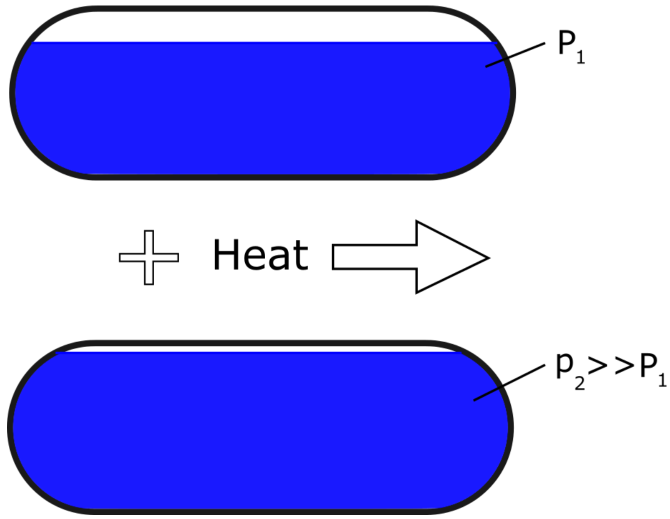

Figure 1: Thermal expansion of the liquid phase and the sequential pressure increase.

One way to counteract this process is to implement an active cooling system that's designed to remove heat from the liquid oxygen. There are several plausible ways to do this but in the end there is only one viable solution, the use of cryocoolers. Cryocoolers are like refrigerators on steroids, reaching temperatures well below 50 Kelvins or even close to absolute zero. The coolers themselves are mechanical contraptions that are mainly utilizing some form of the reversed Stirling cycle to produce a cooling effect. Dumbed down to the bare essentials, a cryocooler can be described as a metallic rod where one side gets extremely cold.

It has been proven that a cryocooler can be used in a submarine to counteract the thermal expansion and thus the need to dump oxygen.

This will also make it possible to increase the so called fill rate in the oxygen tanks. Because if no thermal expansion takes place there is no longer any need for space reserved for this. With other words; the space reserved for thermal expansion can after the implementation of a cryocooler be used to store liquid oxygen instead.

Of the many viable cryocoolers a Stirling based cooler was more or less proven to be the best alternative.

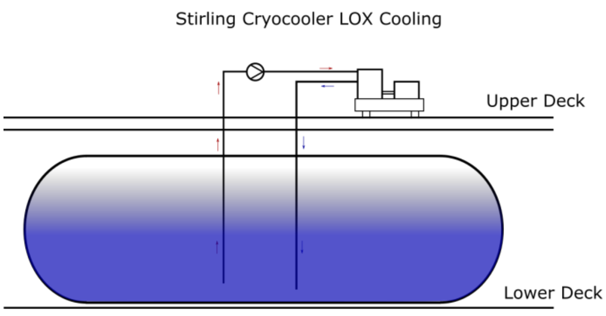

Figure 2: Stirling based cryocooler connected to one liquid oxygen tank aboard a submarine via an external loop.

It is also important to be able to monitor the exact liquid level inside the oxygen tanks. Without this capability it would be hard to verify the cooling systems functionality and the amount of available oxygen at any given time. While measuring the liquid level in a cryogenic environment is trivial this specific situation did prove to be extremely challenging. The safety factors and margins aboard a submarine simply make implementing a level senor next to impossible. External changes and week points in the liquid oxygen tanks are not allowed and sequentially most of the otherwise viable measuring technics are put in the "absolutely-no-way-zone". My point is illustrated in figure 3.

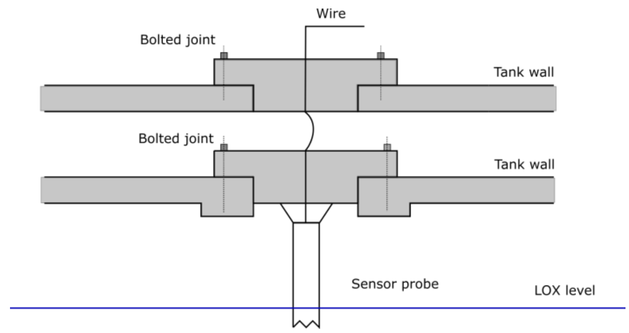

Figure 3: The recommended installation approach for a typical level sensor inside a cryogenic tank; absolutely terrible for use aboard a submarine on the behalf of the safety factors in use.

Instead one has to install the level sensor fully mounted inside the tank, completely inaccessible, without service hatches. This means that the sensor must be operational, without service for the entire life of the submarine and be able to withstand the cryogenic environment inside the tanks. The only sensor that may be able to do this is a capacitance based sensor. The principle is that the property of a weak current through the sensor is changing depending on how much of the sensor that´s submerged in the liquid. By monitoring this current the liquid level can be determined with high precision.

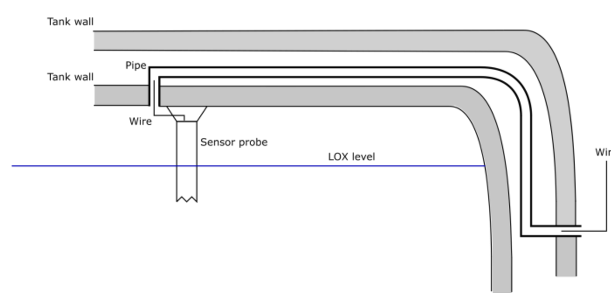

Figure 4: One viable sensor installation design.

To summarize, implementing a Stirling based cryocooler will now only increase the flexibility but also the underwater endurance of a conventional submarine. Measuring the liquid level is complicated but at the very least doable by using a capacitance based sensor.