Overview of open-loop circulation

Introduction

Open-loop circulation takes place when a recirculating bath, chiller or any type of recirculation system (i.e., temperature control unit or TCU) has a temperature controlled reservoir or bath that is open to the atmosphere (open at top) and pumps that move fluid into another bath or container that is also open to the atmosphere (Figure 1).

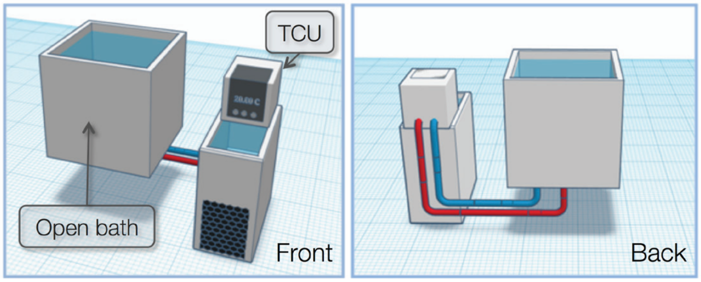

Figure 1. Open-loop circulation. It is commonly believed that an external open bath can be temperature controlled by merely having an inlet and outlet in the side or bottom and connecting them to a recirculating bath or chiller.

While open-loop circulation may seem to be an easy way to add temperature control to an existing fluid bath or trough that may be built to special dimensions for a specific use, it is not.

Many recirculating bath manufacturers suggest that their recirculating baths are “ideal” for this use, but without proper selection and setup, they will not work. We will look at the causes, cures, and best practices for making open-loop circulation as robust* and safe as possible.

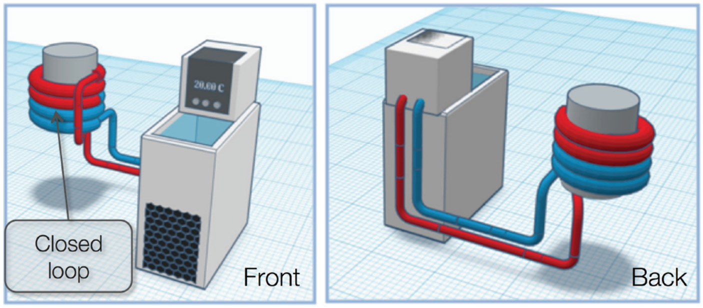

Figure 2. Closed-loop circulation.

Mechanistic comparison of closed- and open-loop circulation systems

In a closed-loop system where only the TCU bath or chiller reservoir is open to the atmosphere (the cooling/heating loop of the tool or system is sealed or closed), the pump that pushes the fluid flow through the system also pushes the fluid all the way back into the TCU (Figure 2).

Conversely, when the circulating loop is open, as shown in Figure 1, a second pump is required to push or pull the water from the system back into the TCU. Many recirculating baths are equipped with force and suction pumps where two pump heads run on the same motor shaft. One of the pumps is plumbed to push the fluid out (force) and the other is plumbed to draw fluid back (suction). Simply relying on the pumps to flow similarly in both directions results in either an overflow or draining of the TCU at best, and at worst, may damage the TCU (Figure 3). It is worth noting that recirculating chillers are typically not designed for open-loop circulation and do not have a return pump.

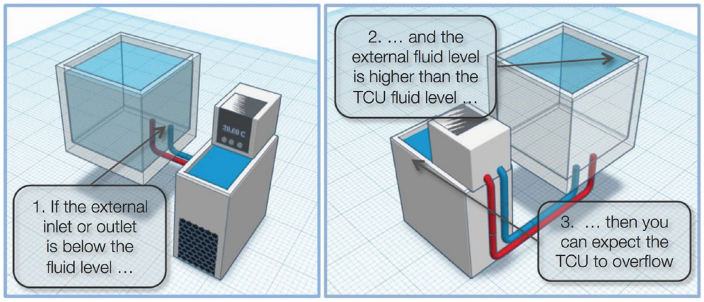

Figure 3. Unbalanced flow and inlet/outlet location will eventually cause overflow during operation and siphon-induced overflow when off.

If the principles of gravity have not been considered during the setup of a TCU, siphoning from the higher bath will occur during filling of the TCU. The two baths need to be positioned such that, when filled, the fluid in both baths is at the same level. Another way is to position the inlet and outlet of the external bath above the fluid level, so they do not create a siphon (Figure 4).

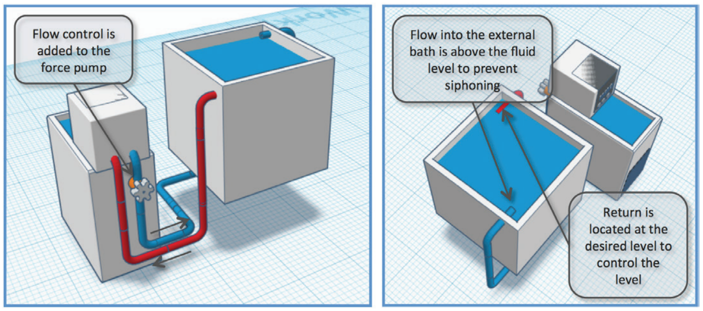

Figure 4. Balanced open-loop circulation.

Once installed, filled, and turned on, typically, the recirculating bath drains and shuts itself off due to a significantly low fluid level—the reason being that the force pump is more powerful than the suction pump. Even though the force and suction pumps share a motor and use the same impeller, the flow rates will still not match. This is because pumps are more efficient when pushing (force) than they are when pulling (suction). How effectively a pump can pull is defined by the Net Positive Suction Head (NPSH).**

A typical fix for this situation is to put a flow-control valve on the force pump to reduce the flow to match the suction pump. However, a small imbalance in flow may still build up over time, resulting in differing fluid levels. Depending on the extent of the imbalance and the time period for the process to be finished, this may or may not be a problem. If it is a problem, then the solution will require a change in the setup of the supply and return fittings on the external tank. It is critical to relocate the return or suction line to have its opening located at the desired depth, then adjust the force pump so that its flow rate is always marginally less than the rate of suction. When adjusted properly, the suction pump pulls some air, but not enough to lose the prime. Slowing the pump speed setting may also make it easier to balance and/or provide more time before either bath reaches a critical fluid level.

Optimization of open-loop circulation flow

Use of heat exchanger

For open-loop circulation to work, nothing but the smallest objects or vessels can be added or removed during the operation for the following reasons:

- When you add something to the external bath, the fluid level goes up and will increase the return flow to the TCU, causing an overflow
- When you remove something from the external bath, the fluid level drops, likely causing a low-level condition in the TCU

For applications requiring the addition and/or removal of objects or vessels, it is best to use an internal or external heat exchanger. An internal heat exchanger typically consists of coiled tubing in the external bath (Figure 5) or any variety of heat exchanger, for example, tube-in-tube, plate, etc. For an external heat exchanger, add a secondary pump located between the open bath and external heat exchanger to create a double-closed loop (Figure 6). This method also works with chillers and recirculating baths that only have a force pump. This is the most robust method where overflows cannot occur.

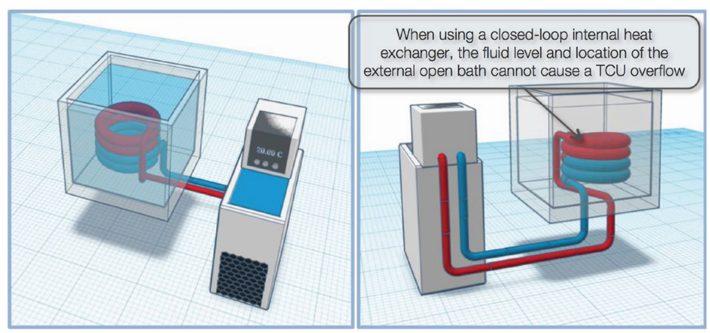

Figure 5. Internal heat exchanger with coiled tubing (closed loop).

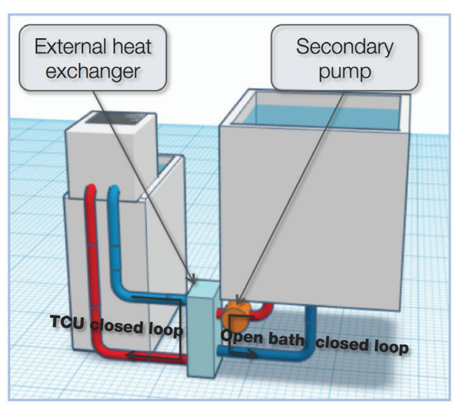

Figure 6. Double-closed loop with external heat exchanger and secondary pump.

It is worth noting that using a heat exchanger may require a temperature setpoint adjustment on the TCU (temperature offset) to achieve the desired temperature. A remote sensor can often be added to the external bath to ensure that the desired temperature is achieved.

Return flow by gravity

Another robust method to improve the performance of open-loop circulation is to use gravity return. This is achieved by mounting the TCU lower than the external bath and having an oversized return line (large ID) come from the side of the external bath at the appropriate depth. When the fluid reaches the external bath return tube the fluid flows directly into the TCU bath rather than coming in through the restrictive return fitting (Figure 7).

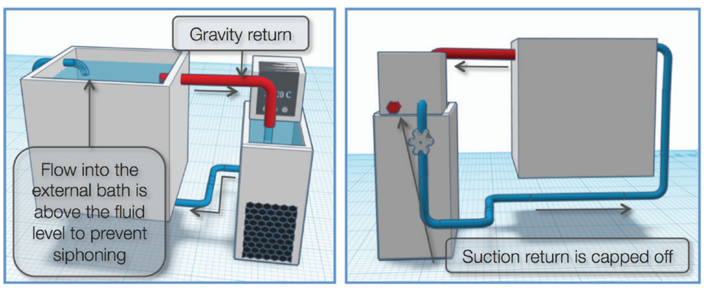

Figure 7. Return flow by gravity.

Gravity return may also be utilized on chillers that have a cooling coil or evaporator coil in the tank or reservoir (Figure 8), but may not be used on chillers that use a plate exchanger or other type of heat exchanger that is not in the tank or reservoir. Attempting open-loop circulation on these types of chillers may result in freezing, causing complete loss of the refrigeration system that will not be covered by the warranty.

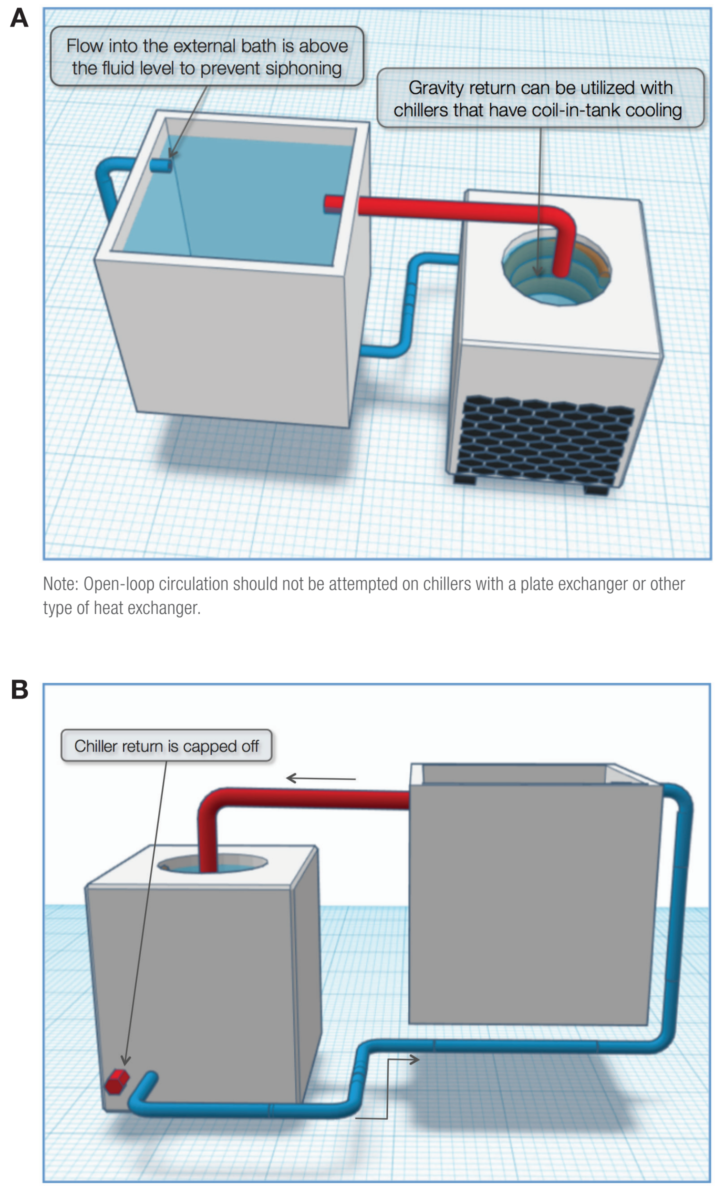

Figure 8. Gravity return on chiller with coil-in-tank cooling. (A) Front and **(B)** back views.

Conclusion

There are several crucial factors that come into play for the open-loop circulation system to work successfully. Location of the supply and return fittings are critical to balancing the force and suction flow rates, and avoiding siphoning. The balance of flow can be made easier with a flow-control valve and a reduction in pump speed. Return flow by gravity works well on recirculating baths and chillers with coil-in-tank cooling. Taking these factors into consideration, it is advised to avoid using open-loop circulation whenever possible. Using a heat exchanger where closed-loop circulation can be maintained is the most robust method to achieve optimized flow control and is highly recommended.

* "Robust" refers to a system that can be left to run on its own for long periods of time without draining, overflowing, or shutting down.

** Net Positive Suction Head (NPSH)—NPSH can be defined as two parts:

- NPSH Available (NPSHA)—the absolute pressure at the suction port of the pump
- NPSH Required (NPSHR)—the minimum pressure required at the suction port of the pump to prevent pump cavitation

NPSHA is a function of your system and must be calculated, whereas NPSHR is a function of the pump and must be provided by the pump manufacturer. NPSHA must be greater than NPSHR for the system to operate without any pump cavitation. In other words, you must have more suction-side pressure available than the pump requires.

Pump cavitation occurs when the pressure in the pump inlet drops below the vapor pressure of the liquid. Vapor bubbles form at the inlet of the pump and are moved to the discharge of the pump where they collapse, often taking small pieces of the pump with them. Cavitation is often characterized by:

- Loud noise often described as grinding or "marbles" in the pump
- Loss of capacity (bubbles take up space where liquid should be)
- Putting damage to parts as material is removed by the collapsing bubbles

Please refer to **pumpschool.com/applications/NPSH.pdf** for more information.

Find out more at **thermofisher.com/bathcirculators**

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