

Sample Temperature during High Throughput Ambient Temperature Centrifugation using Sigma 4-5L

White paper

Design considerations and characterization of the Sigma 4-5L in high-throughput applications. The instrument was tested in a standard configuration, and under realistic conditions with repeated cycles and loading of fresh blood-collection tubes as is typical for clinical lab applications. After optimization based on air flow simulation the temperature increase during centrifugation was minimized to 4.3 °C.

The laboratory centrifuge Sigma 4-5L (IVD) is designed specifically for high-throughput centrifugation. Up to 140 tubes loading capacity and an optional *biosafe* lid for the buckets make it an ideal solution for clinical lab applications.

The instrument is equipped with a new, high-torque drive system featuring outstandingly fast acceleration. Airflow simulation, as used in aerospace-technology, has been employed for optimization of the cooling efficiency and for an impressively low noise level. Minimizing the temperature rise during centrifugation in high work load applications, i.e. maximum protection of blood samples from undesired temperatures, has been the focus of the development, and is the main topic of this whitepaper.

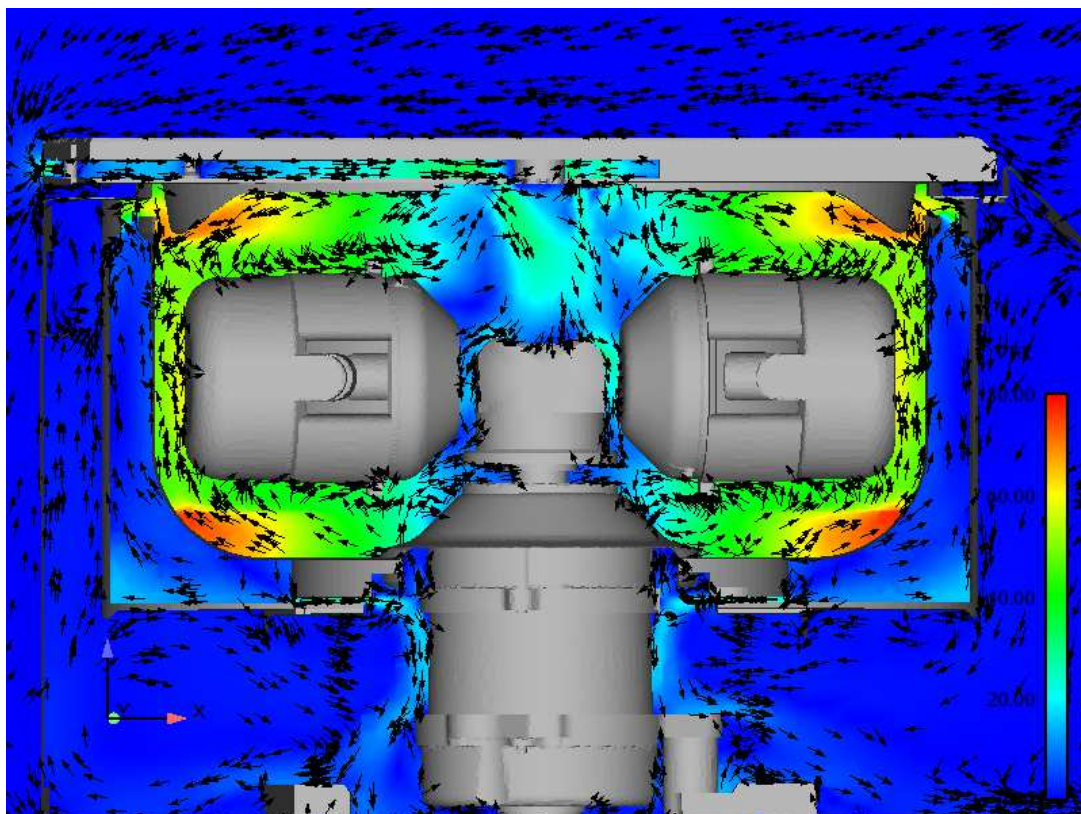


Fig. 2 (top): Rotor 11660, buckets 13460, biosafe lid. Fig. 2: Air flow pattern simulation of Sigma 4-5L

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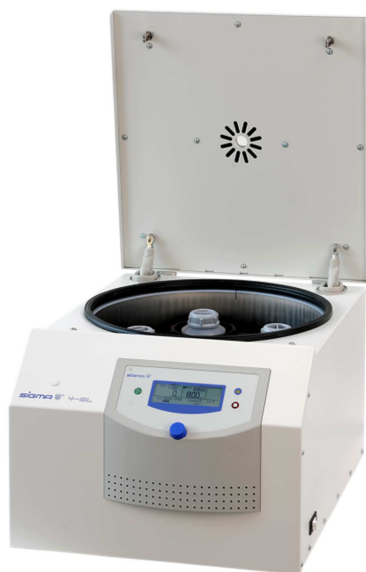
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1. Air circulation optimized based on simulation

Temperature sensitive samples require control of the temperature during sample processing, including centrifugation. This can be easily guaranteed by using a refrigerated centrifuge, which however is significantly more costly than an ambient centrifuge. An ambient centrifuge can be used for more tolerant samples, even in most clinical applications. However, the risk of exceeding the allowed maximum temperature is frequently ignored. The centrifuge manufacturer can contribute to the quality management of the laboratory by providing precise characterization of the temperature increase during centrifugation under relevant conditions, a highly efficient air circulation inside the centrifuge, or a temperature measurement.

Friction with air creates heat. Just like a meteor, which starts to glow due to friction with air upon entering the atmosphere, a fast spinning rotor in a centrifuge will warm up; at a lower level though. This creates the need for cooling inside the centrifuge chamber. The electrical power used for driving the rotation of the rotor is working against the friction with the air, and thus eventually the electrical energy is pretty much completely converted into heat.

Refrigerated centrifuges offer an optimum in sample temperature control, which is important for temperature sensitive samples. The chamber with the rotor is closed and sealed during



centrifugation in order to avoid the buildup of a layer of condensed water or ice inside the chamber. The tightly closed centrifuge lid helps to contain the noise created spinning rotor, and in turn results in relatively quiet operation, provided the refrigerating system is working quietly as well. This advantage however comes at a high price, since the cooling system is responsible for a significant part of the cost of a refrigerated centrifuge. Such a cooling system is technically comparable to a household refrigerator, but designed for working against a constant source of heat. In addition a refrigerated centrifuge comes with a larger footprint and more weight than an instrument with air circulation cooling.

An ambient centrifuge uses the flow of air through the instrument to accomplish three important tasks at the same time – limitation of the rise of the sample temperature to a minimum, and cooling of the motor as well as the drive's power electronics. Since a significant amount of air has to enter and leave the instrument in order to facilitate the transport of heat out of the instrument, ambient centrifuges are prone to be much noisier.

How can an ambient centrifuge be designed for realizing a minimum rise in temperature? Addressing this task is also connected to minimizing the level of noise during centrifugation,

and involves optimization of the flow of air. This may be compared to designing an airplane, which would be tested in a wind canal in combination with an extensive effort in computer simulation. In fact the circumference speed of a laboratory centrifuge rotor easily reached several hundred km/h and thus can be compared to the speed of an airplane.

Air flow simulation technology has been used for optimizing the Sigma 4-5L centrifuge. The Sigma 4-5L is a working-horse designed for high throughput work for instance in a clinical lab environment. The instrument spins up to 140 tubes and features a high torque motor for fast acceleration and long life. Every aspect from air intake, noise shaping, air inlet, air transfer from the chamber to the interior, air flow around motor and electronics to and out of the exit openings has been investigated thoroughly. This requires input of the complete instrument design with rotor and buckets into the simulation program.

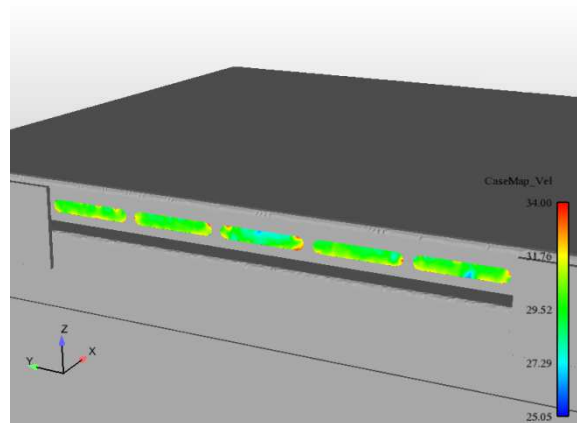


Fig. 4a/b: Air flow pattern simulation has been applied for achieving optimum effectiveness of the air circulation through the instrument. The color coding visualizes the air speed in the air-intake of the Sigma 4-5L centrifuge.

The centrifuge rotor is driving the air flow through the unit. During rotation of the rotor air is pushed away from the center to the outside, and at the same time a low pressure area is created in the center. With an air inlet provided at the center above the rotor, and an outlet somewhere else the centrifuge is practically acting as a fan pumping air. It is therefore also easily understood that blocking the in- or outlet of air of an air-cooled centrifuge will potentially lead to overheating.

The air intake is of particular high importance for minimizing the noise. In addition to the measurement of the noise level in dB(A), the type of noise is relevant for whether it is perceived as a nuisance, or as acceptable for a laboratory working environment. While the noise is in focus at the air intake, the air resistance and flow volume optimization moves into focus when optimizing the geometry inside the lid of the centrifuge. The air is then released into the centrifuge chamber above the center of the rotor. The shape here serves as nozzle and distributor

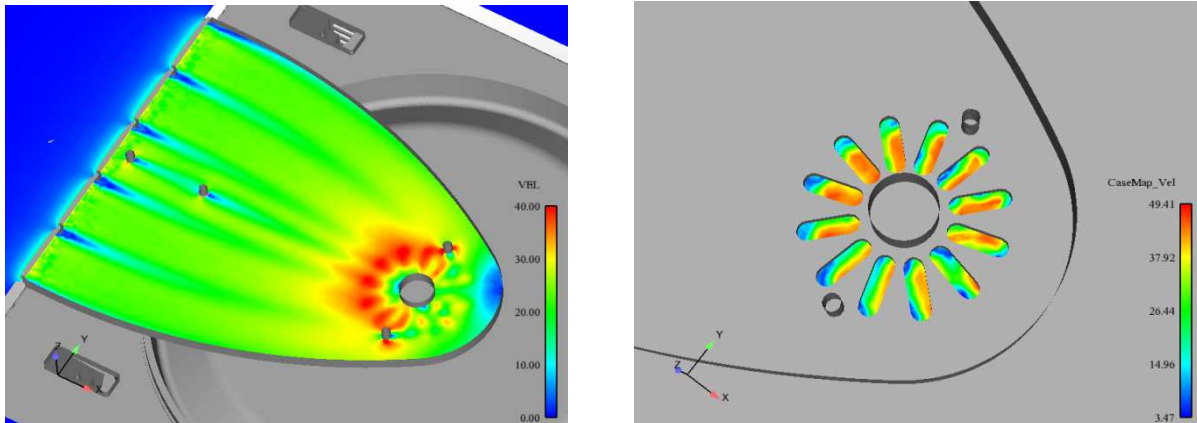


Fig. 5a/b: The color coding visualizes the air speed from the air-intake through the inside of the centrifuge lid (left) to the point where the air is distributed while entering the centrifuge chamber (right) of the Sigma 4-5L centrifuge.

During rotation the highest air speed, causing friction and warming, is at the bottom of the buckets. This speed is proportional to the radius and can easily reach several hundred kilometers per hour.

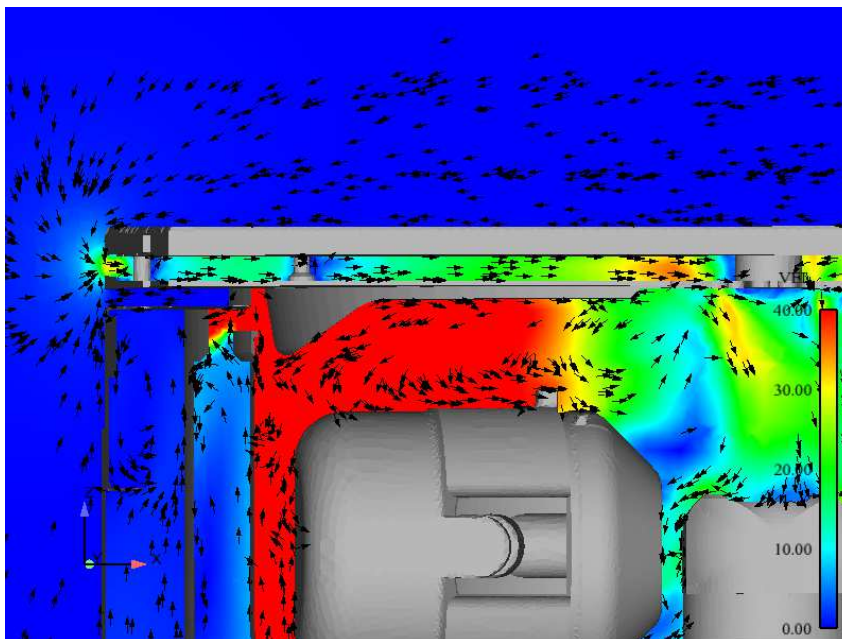


Fig. 6: The color coding visualizes the air speed and gives an indication of the heating due to friction. Ambient temperature air is entering near the center of the rotor. During rotation the maximum speed is at the bottom of the buckets, i.e. at maximum radius. Hence the color also gives an indication of the temperature rise created during centrifugation.

2. Sample Temperature during High Throughput Centrifugation

Centrifugation at high rpm will lead to a warm-up of the rotor and the samples in any centrifuge, even refrigerated models. The degree of warming is very much depending on the maximum speed and shape of a rotor, i.e. is typically different for each rotor, which can be used in a centrifuge. It is a good practice followed by many centrifuge manufacturers to publish the maximum degrees of increase at maximum rpm in the operating manual of the centrifuge. (Sometimes reduced rpm are also mentioned, at which a certain temperature can be maintained, e.g. 4 °C in a refrigerated centrifuge. Sigma Laborzentrifugen GmbH applies a dedicated 4 °C-label to those refrigerated centrifuges capable of holding 4 °C with all rotors at their rated maximum speed.) The temperature increase can range from a few degrees to more than 15 °C. As a consequence, delicate samples could be adversely affected, and in case of in-vitro diagnostics this bears the risk of a negative influence on the results. The results described here are specifically targeting high-throughput clinical lab work. The measurements were performed in the test lab of Sigma Laborzentrifugen GmbH at an ambient temperature of 22.7 °C using a standard Sigma 4-5L equipped with a typical rotor configuration: 11660 with four buckets 13460 (w/o lids), adapter 18460 and standard tubes Ø 17 x 100 mm (PPCO, 14 ml rated loading capacity). The test procedure consisted of 10 cycles of 15 min. runs at 2500 x g (3515 min⁻¹): Loading ambient temperature tubes (2.5 min) -> run (15 min.) -> temperature measurements (5 min.) -> unloading (2.5 min.) -> repeat.

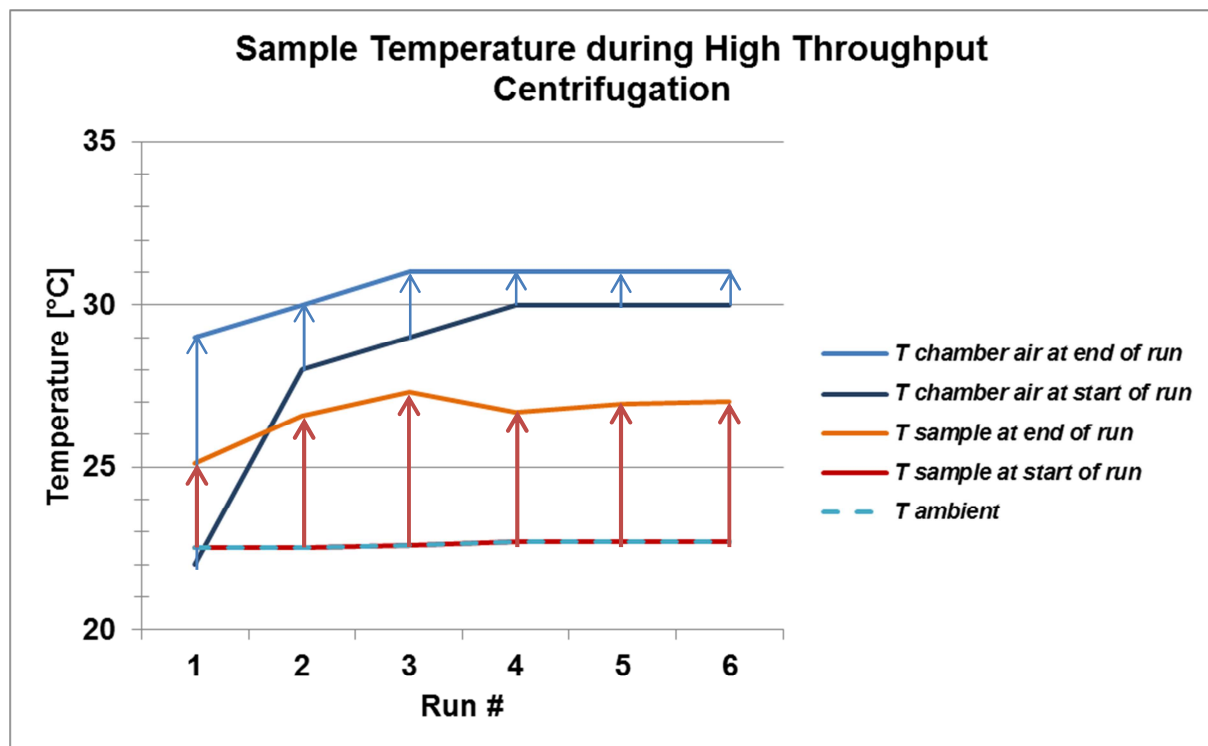


Fig. 7: The temperature rise of fresh samples was measured after repeated 15 min. runs (6 out of 10 runs shown here). The instrument reaches steady-state after about 3 runs, i.e. 45 min. total run time. The maximum temperature increase of the fresh sample (difference between red and orange line) was 4.3 °C, which is an impressively low value for an ambient, air-cooled centrifuge.

For each run 5 tubes per bucket were loaded in a row along the radius. This represents a worst case scenario, since only a small number of tubes at ambient temperature are inserted prior to each run. At the same time this setup allows a very precise analysis of the temperature distribution inside the centrifuge. While the rotor is swung out during the run, some tubes are close to the lid and some close to the bottom of the centrifuge chamber. These two areas are different in that the intake of fresh air is below the lid, i.e. preferred cooling of the tubes is realized near the top, while the bottom of the chamber is closer to the motor and also can be more problematic in terms of lower air circulation.

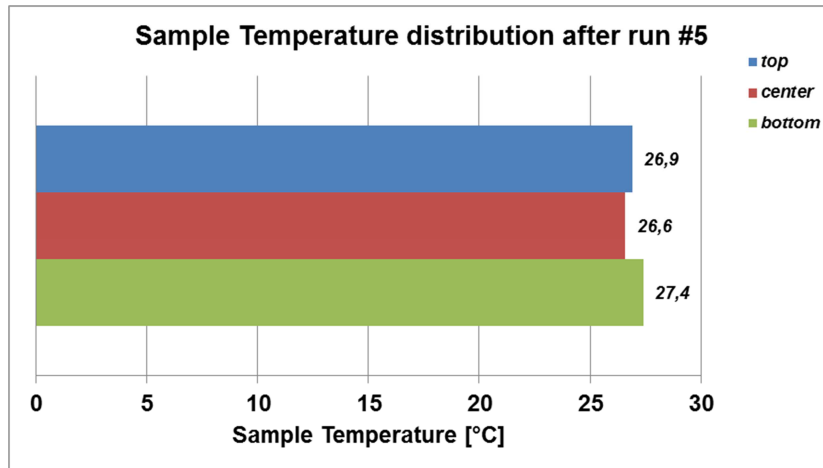


Fig. 8: The temperature variation between tubes inside the same bucket is negligibly small. The example shows the result after run#5. As expected the tube near the bottom experiences a slightly higher rise of temperature compared to the rest, +0.8 °C above the center position. The tube in the top position is typically measured at lower temperature, but here at +0.3 °C above the center position; this is owed to the level of friction associated with the box shape of the 13460 bucket.

Summary

In tests performed under realistic conditions of high-throughput clinical work, as described above, the maximum temperature increase observed with fresh samples in steady-state high throughput work was 4.3 °C. This is an impressively low value.

A full characterization of the temperature rise during centrifugation under conditions, which are typical for clinical work, is often not available. The results above provide information on safe operation conditions in the Sigma 4-5L for the centrifugation of sensitive samples under stringent quality standards. Such demanding quality standards are for instance applied in in-vitro diagnostics applications.

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