WHITE PAPER No. 115

Power Consumption of Microcentrifuges

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Executive Summary

Beyond classical features like silence, speed, and simplicity, centrifuges nowadays are accompanied by sustainability topics like power consumption, energy saving, and reduced usage of resources during production. In this White Paper, we present several power consumption scenarios related to Eppendorf centrifuges in respect to different models. Power consumption of instruments is also important for carbon footprint calculations within laboratories.

Introduction

As with other technical equipment, many buyers like to compare the performance of a centrifuge before deciding to purchase one model over another. This approach is logical as even smaller centrifuges are an investment that is meant to last for the next 10 years or longer: Performance over time has significant impact on overall cost of ownership. In general, there are three major aspects of interest for the user: reliability, (sample and user) safety, as well as sustainability, including energy consumption.

One key element of improved sustainability is the reduction of greenhouse gas emissions. When checking the carbon emissions within the life-cycle of a centrifuge, different aspects appear on the list: Even without a detailed Life-Cycle-Analysis, there are obvious hotspots of carbon emissions. On the production side, there is the resource and energy intensive production of raw materials like steel and copper. On the usage side, there is the power consumption in the laboratories. One of the most serious contributions to greenhouse gas emission results from the energy consumption of products over time. Therefore, we focus on developing new product features that reduce the energy required to operate our products. As a result, the lower power consumption during usage of the centrifuges results in a lower power bill but also reduces the carbon accounting of the facility by reduced Scope 2 emissions in the laboratories.

Development
The technical performance of a new centrifuge is optimized during the R&D process. Afterwards, these data are validated. During the development phase of a new Eppendorf centrifuge, constant checks are performed in-house, by standard. These numerous tests are executed in dedicated environmental chambers (with controlled temperature and humidity) in the R&D departments to understand and optimize the performance of our centrifuge prototypes. Changes in sealings, chamber insulation, or the location of the cooling coils - all have an impact on the performance. The definition of the test equipment is key for exact measurements. It is important to document the equipment used and to ensure regular checks and certification of the test equipment.

Determination for power consumption
With today’s high energy costs and increased focus on environmental consciousness, energy conservation has become even more important in the laboratory. But how much energy is needed for the spinning process? What is the impact of the cooling system?

The power consumption of a centrifugation run relies on multiple different parameters:

> Environmental temperature
> Ventilation capacity around the instrument
> Type of centrifuge
> Type of rotor
> Speed
> Run-time
> Temperature in the rotor chamber
> Loading (distribution and weight)
> Type of vessels
> Temperature of samples

Consequently, there is no general consumption value possible for a specific type of centrifuge. All published consumption values must be defined by at least rotor type, speed, temperature, and time.

Comparisons lack standardization
The comparison of energy consumption of different centrifuges is challenging as there are no global standardized testing conditions in the field of centrifuges. Fuel consumption of cars is nowadays based on the WLTP (world harmonized light-duty Vehicles test procedure), washing machines or similar household devices in the EU have the color code-based ranking, but the testing of centrifuges (as for most other lab instruments) is not defined. For laboratory products like ULT freezers, there is a clear tendency to use ENERGY STAR® as a reference for power consumption. ENERGY STAR, well-known from consumer goods validations, is a testing agency of the United States Environmental Protection Agency (US EPA). But this is so far limited to cold storage equipment in the laboratory and -quite important- limited to 115 V as reference voltage.

My Green Lab®
My Green Lab’ s mission is to improve the sustainability constantly and permanently within research labs. As a non-profit organization, My Green Lab focuses on joining and leading a broad community in the laboratory towards a world in which all research projects reflect the highest standards of social and environmental responsibility.
The organization, founded in 2013, is an international agent for change and improvement in respect to sustainability in laboratories worldwide. Self-described as “Run for scientists, by scientists”, My Green Lab develops standards for greener labs and lab products. One major element of My Green Lab is the ACT® label.

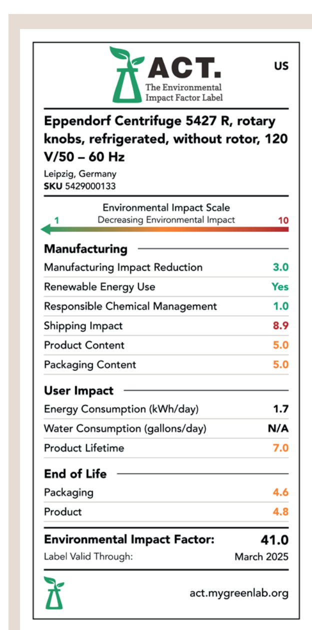

Figure 1: Example of an ACT label (for Centrifuge 5427 R) for sustainability footprint validation

ACT Label

Combining accountability (A), consistency (C), and transparency (T) in respect to manufacturing, energy consumption, water usage, packaging, and end-of-life disposal, the ACT label provides an easy and intuitive way to evaluate the sustainability of a selected product. The product is validated and scored based on different "Environmental Impact Factors" (EIFs), including energy consumption. The scoring of the individual data is performed by the independent organization Sustainability Made Simple Collaborative (SMSC) and then verified and published by My Green Lab. The total score is finally summed up. In principle, the ACT label is a scoring card about sustainability.
The label can be read like a nutrition fact label or like the European performance card for a washing machine or dish washer. The ACT label shows how products 'rate' in different sustainability-related categories by value, which is supported by a color-code of red to green to indicate a specific value class. Several Eppendorf centrifuges have an ACT label.
For more details, please refer to White Paper 087.

Type of rotors

Fixed-angle and swing-bucket rotors are the most common types of rotors used in microcentrifuges and multipurpose centrifuges. The type of rotor has an impact on the power consumption due to weight and air resistance.

Swing-bucket rotor

This kind of rotor consists of a rotor cross with buckets that swing out horizontally during centrifugation and swing back into a vertical position when the centrifuge comes to a stop. The movement of the swing-bucket parts creates increased air resistance. Smaller swing-out rotors are equipped with air-shields to reduce the resistance and by this the power consumption. Due to its size, swing-bucket rotors are primarily limited to bigger centrifuges.

Figure 2: Swing-out rotor for centrifuges

Fix-angle rotors

Unlike swing-bucket rotors, these rotors spin the samples at a fixed angle, mostly between 20° and 45°. Fixed-angle rotors have no moving parts. This means lower metal stress, which allows using a higher maximum g-force and lower relative energy consumption.

Figure 3: Fixed-angle rotor for centrifuges

Testing procedure

As mentioned, there is no standard for power measurements of centrifuges, in the process of ACT labeling of some Eppendorf centrifuges, we determined to develop in a combined approach with My Green Lab a testing procedure for power measurements of laboratory centrifuges. The agreed testing procedure provides power consumption data of a typical usage pattern in the laboratory. To gather realistic data, we have decided to take different factors, that have an impact on the energy consumption in various settings into account. In the process of data gathering, further values were measured which we selected for publication in this White Paper.

Microcentrifuge: Fixed-angle rotor

> **Fixed-angle rotor for 1.5 mL conical tubes; 24-place rotor**

> **Room temperature:**
20°C +/- 2°C

> **First test (Precooling):**
> Precooling (FastTemp) to +4°C
> Centrifuge incl. rotor + rotor lid
> Measurement of energy incl. closing of centrifuge lid, acceleration, deceleration, opening of centrifuge lid

> **Samples:**
> 10x tubes 1.5 mL microtube, filled with 1.0 mL water
> Sample temperature: 4°C (pre-cooled)
> After precooling run: Split of conical tubes into rotor, symmetric positions in 2 groups

> **Second test (Run):**
> Centrifuge is pre-cooled to +4°C
> Settings Centrifuge: 20 min; 20,000x g; 4°C
> Centrifuge incl. rotor + rotor lid + sample tubes
> Measurement of energy incl. closing of centrifuge lid, acceleration, deceleration, opening of centrifuge lid

> **Third test (Run):**
> Centrifuge is pre-cooled to +4°C
> Settings Centrifuge: 60 min; 20,000x g; 4°C
> Centrifuge incl. rotor + rotor lid + sample tubes
> Measurement of energy incl. closing of centrifuge lid, acceleration, deceleration, opening of centrifuge lid

> **Temperature recovery of centrifuge and rotor back to room temperature for at least 3 hours before next Precooling run**

These testing conditions were verified by My Green Lab to guarantee a fair and transparent set-up. The testing was performed with several runs on the same unit as well as – whenever possible – with several instruments of the same type.

Results
The following data were documented based on single or several instruments of the same type. Values were measured at least twice to check variability. This White Paper addresses the data beyond the ACT-related testing procedure which is limited to 20,000 x g [rcf].

In contrast to the bigger multipurpose centrifuges, the smaller but faster microcentrifuges are used in a different pattern. The smaller and lighter rotors in combination with higher speed result in lower power consumption compared to the big centrifuges, that mostly handle higher sample volumes. Depending on the size of the microcentrifuge, the power consumption differs as the engine as well as the cooling system are optimized for the specific instrument size, it´s sample capacity, and usage pattern.
Figure 4 shows the power consumption of 20 min runs at different g-forces without refrigeration. The distribution between 5,000 and 20,000 x g is approximately linear. This enables the estimation of power consumption values for other rcf. The extrapolation is realistic for non-refrigerated instruments whereas the cooling by compressor within refrigerated centrifuges has an impact on this extrapolation.

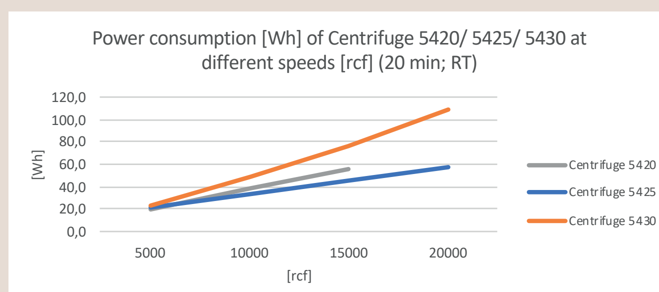

Figure 4: Power consumption of different non-refrigerated microcentrifuges (Centrifuge 5420, 5425, 5430) with 24-/24-/30-place rotor and 10x 1.5 mL microtubes at different g-forces (rcf)

The Centrifuge 5420 is optimized for low-speed applications but consumes more power at higher speed compared to the more versatile Centrifuge 5425. The Centrifuge 5430 has a strong engine for high-speed up to 30,000 x g (depends on type of rotor). This requires a strong engine with higher power consumption also for other rotors and other speeds.

Refrigeration

For most molecular application, 4°C is a standard temperature. To reach this temperature, strong and efficient compressor systems for active cooling are required. The Fast-Temp/ Pre-cooling function is an efficient way to cool down the centrifuge within minutes. The pre-programmed settings enable an energy-saving and fast cool-down of the rotor chamber and the rotor at a dedicated time point.

	[Wh]/ Precooling Centrifuge 5425 R	[Wh]/ Precooling Centrifuge 5427 R	[Wh]/ Precooling Centrifuge 5430 R
Average	30	65	72

Table 1: Power consumption of refrigerated microcentrifuges during precooling/ FastTemp with 24-place (Centrifuge 5430 R: 30-place) rotor and 10x 1.5 mL microtubes

During the run, the compressor constantly runs to counter-cool the friction heat of the spinning rotor. This on-going cooling explicitly increases the power consumption which is used for the spinning process. Figure 5 compares the power consumption data of the two microcentrifuges Centrifuge 5425 and 5425 R.

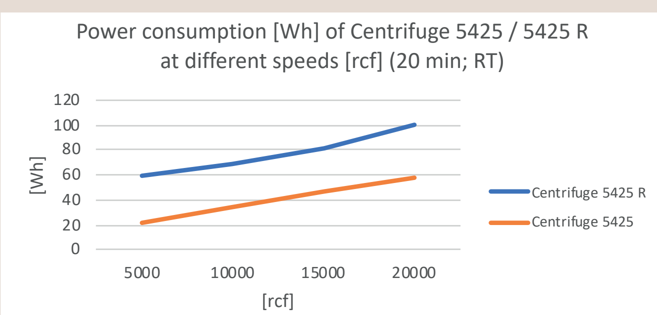

Figure 5: Power consumption of a non-refrigerated Centrifuge 5425 compared to its refrigerated version Centrifuge 5425 R with a 24-place rotor and 10x 1.5 mL microtubes (filled with 1 mL of water) at different g-forces (rcf)

When comparing different sizes of microcentrifuges, the chosen usage-profile impacts the power consumption. The more and longer a centrifuge volume class is used, the more powerful is the installed compressor. This means, e.g., the Centrifuge 5427 R which has a typical usage profile of high sample numbers and longer runs at high speed is equipped with a stronger cooling system compared to a Centrifuge 5425 R which is mainly used for shorter spin-downs of a few samples at the bench.

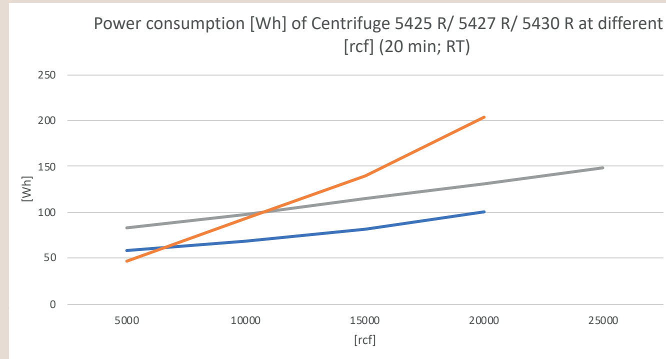

Figure 6: Power consumption of different refrigerated microcentrifuges (Centrifuge 5425 R, 5427 R, 5430 R) with 24-/24-/30-place rotor and 10x 1.5 mL microtubes (filled with 1 mL of water) at different g-forces (rcf) with 4°C

Figure 6 shows the power consumption of 20 min runs at different g-forces with refrigeration for different instrument classes of microcentrifuges. The distribution between 5,000 and 20,000 x g is less linear compared to centrifuges without refrigeration. Runs at higher speed require a higher impact of cooling, consequently consuming more power.

Energy savings

The provided data document the power consumption of centrifuges. To explore ways to reduce this consumption, various options were discussed with the Eppendorf Centrifuge R&D team.
Modern and efficient compressor systems and strong but smoothly running engines improve the power consumption. This is addressed in the R&D process. The primary constraints for energy savings in centrifuges are dictated by physical laws: accelerating the specific weight of the sample, vessel, and bucket/rotor requires a defined amount of energy. Additionally, friction generates heat, which necessitates corresponding cooling to maintain optimal operating conditions. Compressor performance results in specific energy consumption for cooling. Options to limit the power consumption of centrifuges by adjusting their operation are therefore limited and not always reliable.

Reduction of speed with elongated run times

The speed of a rotor in rpm (revolutions per minute) is rather imprecise. The rcf (relative centrifugal force resp. g-force) applied to a sample depends on both the rotational speed and the rotor radius. The same precipitation of a sample can be reached by a lower rcf but requires a longer run time.
By following the subsequent formula, you can calculate the needed time increase when slowing down the speed of the centrifuge:

$$\mathit{Time}_{\text{adjusted}} = \mathit{Time}_{\text{protocol}} \times (\text{rcf}_{\text{protocol}} / \text{rcf}_{\text{adjusted}})$$

To obtain the same separation efficiency, the run of, e.g., a Centrifuge 5427 R could be expanded while lowering the speed. A classic standard protocol for precipitation of DNA (20,000 x g; 20 min) could be slowed down to (10,000 x g; 40 min).

Keep in mind for energy savings:
> Prefer microcentrifuge instead of larger devices for small samples to save energy
> Use the smallest rotor in your centrifuge to reduce the weight and thereby the energy consumption
> Benefit of pre-cooling/ FastTemp functions for fast and efficient cool-down
> Keep the centrifuge lid closed if the unit is pre-cooled to +4°C
> Remove any empty tube or useless counter-weight tubes (but keep the specific counter-weights)

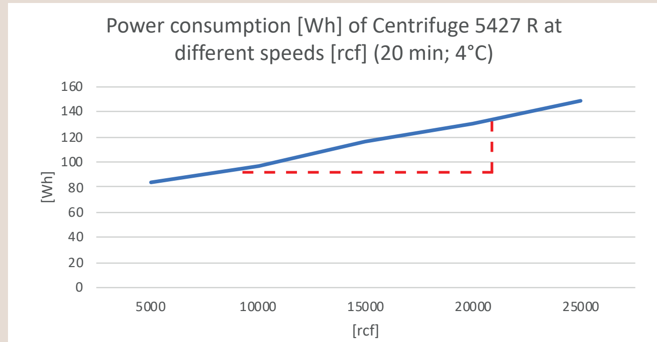

Figure 7: Power consumption of Centrifuge 5427 R with 24-place rotor and 10x 1.5 mL microtubes (filled with 1 mL of water) at different g-forces (rcf); red lines symbolize speed reduction from 20,000 x g to 10,000 x g while doubling the run time from 20 min to 40 min

Figure 7 shows that the change from 20,000 x g to 10,000 x g by doubling the run time results in a power consumption of ca. 190 Wh compared to the original consumption of ca. 130 Wh. The main impact for this result is the longer run time of the compressor. There can be settings where cutting the speed half and doubling the time can result in real power savings but those settings should be exactly tested for efficiency.

Reduction of ramps

A reduction of the acceleration and braking ramps can reduce the power consumption of the device. This reduction is very limited (data not shown) compared to the total consumption of the centrifuge (run + cooling).

Summary

Despite all needs for resource savings, the integrity of the sample is still the most important aspect in any research application. For centrifuges, a weaker cooling compressor consumes less energy but puts samples and experiments at risk.
The scientific community should be aware of the level of power consumption of centrifuges. Especially for calculating their own carbon footprint, institutions and companies should be aware of the power consumption of their equipment. Given the limited power-saving options for centrifuges due to physical laws, the focus should shift from reducing consumption to considering the source of power:

Where does your laboratory's power come from? The more renewable energy you consume, the lesser the environmental impact of the power consumption of your centrifuges.
For several years now, all classic Eppendorf micro- and benchtop centrifuges from our facilities in Germany and USA have been assembled with 100% renewable electric power. Since 2019, Eppendorf has switched the external power supply for all our major factories as well as the headquarters from classic power contracts to 100% renewable ones. These changes cut down our own global carbon emissions by 58% from 2019 to 2022.

About Eppendorf

Eppendorf is a leading life science company that develops and sells instruments, consumables, and services for liquid-, sample-, and cell handling in laboratories worldwide. Its product range includes pipettes and automated pipetting systems, dispensers, centrifuges, mixers and DNA amplification equipment as well as ultra-low temperature freezers, fermentors, bioreactors, CO_2 incubators, and shakers. Associated consumables like pipette tips, test tubes, microtiter plates, and disposable bioreactors complement the instruments for highest quality workflow solutions.
Eppendorf was founded in Hamburg, Germany in 1945.

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