ECAM: A low-cost vaping device for generating and collecting electronic cigarette condensate for *in vitro* studies

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ABSTRACT

The use of electronic cigarettes (ECs) has become widespread despite many unknowns around their long-term health impact. ECs work by vapourising a liquid, known as an e-liquid, typically consisting of propylene glycol, glycerol, flavourings and nicotine. The chemical constituents and resultant impact on cells and tissue are dependent on several factors, including the flavourings used, the vaping topography/use pattern, and the device used. ECAM (Electronic Cigarette Aerosol Machine) is an open source, portable device for creating EC aerosol – for condensate collection and *in vitro* studies - using a controlled methodology. ECAM was developed as a low cost, automated, and customisable alternative to commercial devices. ECAM consists of a micro diaphragm gas pump to draw air/EC aerosol through the system. The device is automated using an Arduino and solenoid pinch valves are used to alternate between air and EC vapour. Condensate is collected in a vial within a cold-water bath. Each ECAM unit uses a temperature/humidity sensor to measure ambient air conditions and a differential pressure sensor to determine the pressure within the system. ECAM is programmed to adhere to International Standards Organisation 20768:2018. The design files, source code, and build instructions for this device can be found at https://dx.doi.org/10.17605/OSF.IO/3NGU4.

Specifications table

Hardware name	Electronic Cigarette Aerosol Machine (ECAM)
Subject area	• Chemistry and Biochemistry • Biological Sciences (e.g. Microbiology and Biochemistry) • Educational Tools and Open Source Alternatives to Existing Infrastructure
Hardware type	• Biological sample handling and preparation • Chemical sample preparation • Electrical engineering • Mechanical engineering
Open Source License	GNU general public license 3.0
Cost of Hardware	*$1247.88 excl. GST (US Dollars)*
Source File Repository	https://doi.org/10.17605/OSF.IO/3NGU4

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NB/ Conversions from New Zealand dollars (NZD) to US dollars (USD) were done using an exchange rate of: $1 NZD = 0.70 USD.

1. Hardware in context

Electronic cigarettes (ECs) are promoted by the industry as a safer alternative to conventional cigarettes; however, the long-term health impacts are not yet known. Several recent reviews summarise studies demonstrating significant evidence that the use of EC devices poses health risks [1–6]. ECs are electronic nicotine delivery systems that work by vapourising a liquid, known as an e-liquid, that the user inhales. E-liquids typically consist of propylene glycol, glycerol, flavourings and nicotine. However, a much broader range of chemicals have been found some of which are known toxicants, including carcinogens and heavy metals [7–10]. Other electronic nicotine delivery devices include devices that heat plant material, these are known as heated tobacco products (HTPs) or heat-not-burn (HNB) tobacco products. Because of the large range of electronic nicotine delivery devices, ECs, and e-liquids available and a lack of standardisation around manufacturing and experimentation, studies analysing the chemical components in EC aerosol have shown variable results. One example of this is the identification of formaldehyde in some studies and not in others, as discussed in this study by Farsalinos et al. [11]. To ensure standardisation across experimental studies, it is important that aerosol-creating devices conform to published standards and that specific vaping topographies can be prescribed, well controlled, and recorded. Vaping topography refers to the pattern of use of the device. This includes the number of puffs, puff duration, puff volume, puff period, and puff profile (pressure drop and flow rate).

Existing commercial devices such as those by Vitrocell [12] and Borgwaldt [13], are expensive (Table 1) and were originally designed for conventional cigarette testing. Some have been adapted to allow for EC testing although they are limited to ECs that only require flow generated at the mouthpiece to activate. Other commercially available devices such as those created by Gram Research [14], do not provide a method for trapping aerosol or meet the pressure requirement section of the ISO standard for vapour products (*ISO 20768:2018*) [15]. Additionally, these machines are expensive, complex and compact, making them hard to customise or isolate problems. With an in-house smoking generation machine, the conditions that are important for the specific purposes of the study can be strictly maintained.

Bathrinarayanan created a bespoke, automated aerosol delivery system, constructed to create and deliver both cigarette smoke (CS) and EC aerosol for *in vitro* exposure experiments [16]. This device was designed to provide flow (EC or CS) at controlled flow rates and durations. Experiments using this device [16] were operated using the standardised puff regime for CS (ISO 3308:2012) due to the absence of the ISO for vapour products [15] during the time of its development.

The purpose of this study was to develop a low cost, automated, and customisable aerosol generation and collection system conforming to *ISO 20768:2018* that could test button activated tank-style ECs and produce consistent and accurate results. The standard conditions specified by the ISO 20768:2018 standard are:

- Puff volume: 55 ml ± 0.6 ml determined at the port of the vaping machine in series with a pressure drop device of 1000 Pa ± 50 Pa.
- Puff duration: 3 s ± 0.1 s.
- Puff period: one puff starting every 30 s ± 0.5 s. Note, puff period is the sum of the puff duration and wait time before the next puff is taken.
- Puff number: must be counted and recorded.
- Puff profile: should be of approximate rectangular shape measured at the port of the vaping machine in series with a pressure drop device of 1000 Pa ± 50 Pa. The volume of the increasing and decreasing portions of the flow profile shall not exceed 10% of the total puff volume.
- The test atmosphere shall be kept within the range 15 °C to 25 °C and not vary more than ±2 °C and between 40% relative humidity (RH) and 70% RH and not vary more than and not vary more than ±5% RH.

2. Hardware description

ECAM (Electronic Cigarette Aerosol Machine) is a compact, portable device controlled by a customisable program for generating EC aerosol with defined flow and topography characteristics adhering to ISO 20768:2018 [15] standard requirements (see Fig. 1). ECAM is designed for use with the button activated Ricky R200 tank style EC or any flow activated EC. ECAM is programmed with a predefined set of test characteristics including the puff number, duration, period, and flow rate. ECAM uses a number of electromechanical components to achieve these. Flow is generated by a micro diaphragm gas pump that is controlled by an Arduino UNO and regulated using feedback from a calorimetric flow meter. The system is capable of adjust-

Table 1
The cost of commercially available devices.

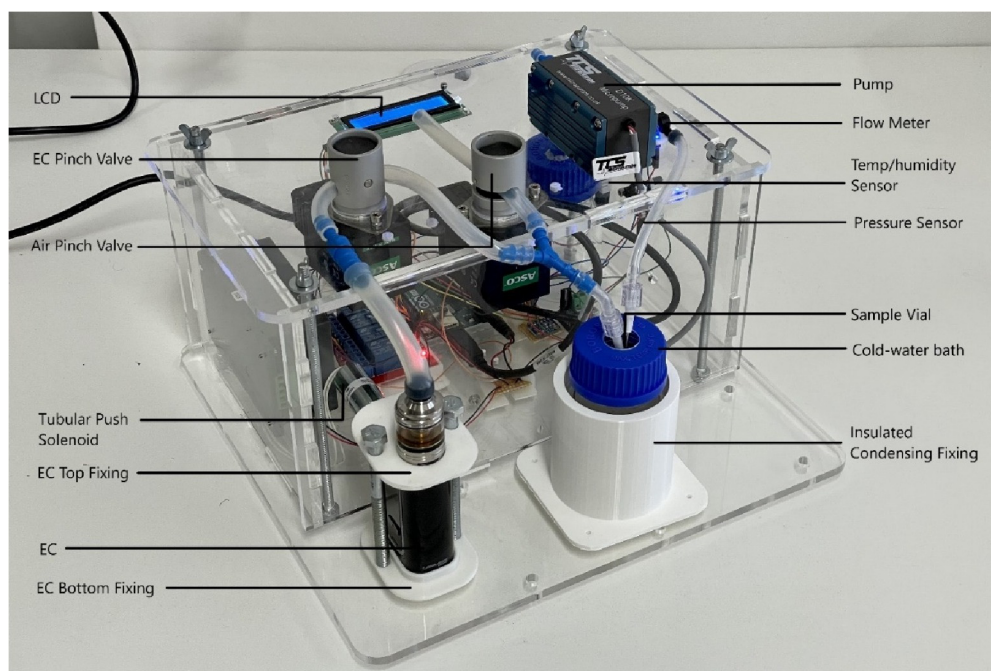| Commercial Smoking Machine	Cost (USD)
Vitrocell VC10	119,099.40
Gram Research	10,000.00

Fig. 1. Annotated view of the ECAM.

ing flow to between 15.00 ml/s and 31.67 ml/s and maintaining it within 0.60 ml/s of the target when tested with a maximum pressure drop (between the EC and the pump) of 3000 Pa and 0.36 ml/s with a 1000 Pa pressure drop. Two solenoid pinch valves controlled by signals from the Arduino via a 24 V relay are used to direct flow from tubes connected to the EC or to the atmosphere to allow for clearing puffs. When testing the Ricky R200, the button is activated simultaneously with the opening of the EC solenoid pinch valve to heat the coil and aerosolise the e-liquid while the flow draws the aerosol out through the mouthpiece. The vapour is collected as a condensate by drawing the aerosol through needles into a vial submerged in a cold-water bath. The efficiency of aerosol collection is 34%. ECAM also uses the DHT22 sensor, a capacitive humidity sensor and a thermistor (to measure the ambient humidity and temperature), capable of measuring 0–100% ± 2–5% relative humidity and −40–80 °C ± 0.5 °C, to determine if ambient air conditions are maintained within ISO 20768:2018 requirements [15].

Other features include:

- LCD screen indicator to display flow rate, temperature and humidity ranges, and number of puffs;
- Aerosol trap using luer fittings, hypodermic needles and a 7 ml vial with a silicone self-sealing cap to isolate the aerosol collected from the atmosphere;
- 24 V 5A power cable;
- Self-contained system: All components are within or attached to the ECAM structure to enable ease of relocation to be within an incubator or fume cupboard;
- Food-grade silicone tubes which do not contaminate samples and are able to be cleaned to prevent contamination between tests without needing to replace the tubes as consumables;
- USB connection to a desktop or laptop computer to change test protocol parameters or collect more detailed data on flow, temperature and humidity fluctuations throughout tests.

A single ECAM unit costs less than 10% of a number of commercially available units, based on quotes received from commercial suppliers mentioned in Section 1 [unpublished data]. ECAM is designed and constructed from commercially available components, 3D prints and laser cut pieces to reduce time and expertise. The ECAM also enables greater customisation than commercially available devices including use of a wide range of EC devices, variation of flow rates, puff duration and frequency, and ability to conduct *in vitro* cell exposure testing in series with condensate collection. Sanitation and cleaning of the system can be done by washing tubes and needles in warm soapy water, disinfecting with a solvent such as ethanol or sterilising using an autoclave. Alternatively, these components can be replaced as consumables for less than USD 3.50.

The ECAM can be used for a number of applications including:

- EC vapour sample collection;
- *In vitro* exposure to live cultured bronchioepitheial or alveolar epithelial cells
- Used in-line with a mouth, pharynx, and larynx or lung models to observe the dispersion of vapour through 3D printed models of the airways during inhalation;
- Particle size analysis, drawing EC aerosol through a particle size measurement device (e.g. Malvern Spraytec) during a controlled vaping topography.

3. Design files

Table 2 lists the files needed for constructing and operating the ECAM unit.

Description of files

The 3D printing files were designed in Solidworks. These files include the native Solidworks files, STEP files which can be opened in open-source CAD programs such as Fusion 360 and STL files which can be directly printed on most 3D Printers. The design files are stored in an online repository (linked in Table 2) that contain wikis of the use of the files and how to download them. The software files are written in Arduino Code. This code is to be used in conjunction with the Arduino software IDE and must be uploaded to the ATMEGA328 microcontroller (the Arduino UNO microcontroller). This code can be used to adjust and control the vaping topography characteristics required to run the test including puff profile, frequency and duration. The laser cutting files are custom drawings compatible with the laser cutter software which are used to cut the acrylic sheets for the machines structure and mounting for components. If no laser cutter is available, these can be cut by hand using a jigsaw and drill.

4. Bill of materials

The materials required for constructing the ECAM system are included in detail in the bill of materials (https://osf.io/9bz36/, part of the detailed build instructions), a reduced list, including the main components and collections of the smaller components is shown in Table 3. Consumables used during the construction and operation of the ECAM are given in Table 4. Details of any specialised tools required are included in the detailed bill of materials. Although these tools are not absolutely necessary to construct the ECAM systems, they significantly increase the ease and efficiency of the construction process. Some items are sold in bulk but only a few quantities are needed.

5. Build instructions

Instructions on constructing the ECAM can be found at https://doi.org/10.17504/protocols.io.bswunfew. The designators used in the build instructions are defined in the bills of materials (Tables 3 and 4).

6. Operation instructions

6.1. Basic operation

6.1.1. Preparing the EC
Before operating the ECAM, the EC must be charged, coil installed, and EC cartridge filled with EC fluid. To change the coil in the Ricky R200 you need to unscrew the entire cartridge from the body, then unscrew the cartridge top from the coil, pull the glass chamber off the O-ring seals, then unscrew the coil from the cartridge base (Fig. 2). The EC should be left for a few minutes prior to commencing testing to allow the wick to saturate with EC fluid. The cartridge should be filled to at least halfway – sufficient to submerge the coil.

Table 2
Design Files for ECAM.

Design file name	File type	Open-source license	Location of the file
3D Printing	CAD	General Public License (GPL) 3.0	.https://doi.org/10.17605/OSF.IO/SC7EB
Arduino	Software	General Public License (GPL) 3.0	https://doi.org/10.17605/OSF.IO/YZMCV
Laser Cutting	CAD	General Public License (GPL) 3.0	https://doi.org/10.17605/OSF.IO/CHVNE
Detailed build instructions	Text	CC-BY License	https://doi.org/10.17504/protocols.io.bswunfew
Video demonstrating operation	Video	N/A	https://osf.io/de3nq/

Table 3
Reduced bill of materials including the main components and collections of the smaller components. The detailed list of all components is available in the full bill of materials in the online repository.

Designator	Component	Number	Cost per unit USD	Total Cost USD	Source of materials	Material Type
A.P	**Pump**					
A.P1	D10K Microdiaphragm gas pump	1	280.00	280.00	https://micropumps.co.uk/DATA/pdf/IM29%20-%20Instructions%20D10k%20REV%203.pdf	Non-specific
A.P2	Eqi-D10K Brushless motor controller	1	81.82	81.82	https://micropumps.co.uk/DATA/pdf/IM063%20-%20Instructions%20EQi-D10K%20REV%201.pdf	Non-specific
A.S	**Solenoids**					
A.S1	Solenoid pinch valvue	2	146.22	292.45	https://nz.rs-online.com/web/p/solenoid-valves/0488756/	Composite
A.S2	Tubular push solenoid	1	62.11	62.11	https://nz.rs-online.com/web/p/tubular-solenoid/1857563/	Composite
A.S3	Solenoid pinch valve connector DIN 43,650 A	2	3.86	7.73	https://nz.rs-online.com/web/p/din-43650-solenoid-connectors/1564757	Composite
A.PW	**Power**					
A.PW1	24 V 5A Power Supply	1	50.52	50.52	https://nz.element14.com/mean-well/gst120a24-p1m/adaptor-ac-dc-24v-5a/dp/2815847	Composite
A.E	**Electrical**		0.00	0.00		
A.E1	Arduino UNO	1	22.97	22.97	https://nz.element14.com/arduino/a000066/arduino-uno-evaluation-board/dp/2075382?st=Arduino%20UNO	Composite
A.E7	Flow meter - Calorimetric 2 L/min	1	99.86	99.86	https://nz.element14.com/integrated-device-technology/fs2012-1020-ng/gas-flow-sensor-2 l-min-5 mm-5-25v/dp/2857822	Composite
A.E8	Temp/Humidity Sensor DHT22	1	12.03	12.03	https://nz.element14.com/mcm/83-17985/dht22-temp-humidity-sensor/dp/2801405?st=83-17985	Composite
A.E9	Pressure Sensor 1PSI, 5 V, SIP	1	46.04	46.04	https://nz.element14.com/honeywell/sscsnbn001pdaa5/sensor-trustability-1psi-5v-sip/dp/1823230	Composite
Collections						
A	Assembly components, see detailed table	–	–	36.37	Various	Various
A.T	Pneumatic components, see detailed table	–	–	77.15	Various	Various

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Additional Information:

All costs stated are excluding GST (in US dollars (USD), GST = Goods and Services Tax and is 15%). The D10K Pump is no longer available. However, this can be replaced by a gas pump that runs on 12–24 V and can produce flow rates of between 15 and 30 ml/s.

Table 4
Bill of materials for the consumables used during the construction and operation of ECAM.

Designator	Component	Number	Cost per unit USD	Total Cost USD	Source
	Consumables				
X1	Sample Vial	0.01	148.46	1.48	https://www.sigmaaldrich.com/catalog/product/supelco/27341?lang=en&region=NZ
X2	E-cigarette Fluid	1	7.00	7.00	https://www.vapo.co.nz/products/pure?variant=35823357320
X3	Ceelon Thread Seal Tape 12 mm PTFE12 (Available In Boxes Of 24pcs)	1	2.04	2.04	https://tradetools.co.nz/collections/thread-seal-tape/products/ceelon-thread-seal-tape-12mm-ptfe12
X4	WELD-ON 16 Acrylic Plastic Cement 146 ml	1	31.27	31.27	https://www.glueguru.co.nz/shop/SUBSTRATES/PLASTICS/Acrylic/WELD-ON+16+Acrylic+Plastic+Cement+146ml.html
X5	Ricky R200 Electronic Ciagarette	1	87.50	87.50	https://www.lawless.co.nz/vaping/advanced-kits/rickyr200/
X6	Isopropyl Alcohol	1	13.99	13.99	https://www.bunnings.co.nz/diggers-500ml-isopropyl-alcohol-cleaner_p1560549

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6.1.2. Setting up the EC and sample vial

To set up the ECAM for operation, place the EC in the 3D printed base fixing and slot the top fixing over the cartridge (Fig. 2). Place the M8 bolts through the holes and screw firmly into place ensuring the side of the EC with the button is facing the tubular push solenoid. The plunger should just be touching the EC when fully seated, this ensures maximum force production. Connect the silicone tube to the mouthpiece of the EC ensuring that the silicone tube creates a seal. To prepare the condensing chamber, remove the lid from the cold-water bath and fill to three quarters with cold water or a dry ice/alcohol slurry. Replace the lid and put into the insulated fixing (ECAM_322). Insert the inlet needle (A.C3) fully into the silicone cap of the vial (A.C1) and the outlet needle to halfway. Then insert the vial into the cold-water bath through the hole in the lid.

6.1.3. Setting test protocol

A USB A/B cable is plugged into the Arduino with the USB A connector available on the outside of the machine. To adjust vaping test conditions, plug the USB A cable into your computer and open the ECAMSystemControl012.ino file in the Arduino

Fig. 2. Annotated Ricky R200 EC showing cartridge components.

IDE (Fig. 3). You will need to specify the board **S1**, port **S2** and programmer **S3** by going into Tools, select Arduino UNO, COM X (Arduino UNO) and Arduino ISP. The COM port number will be specific to your computer. Set the values for puff number **S4**, duration **S5**, period **S6**, and flow rate **S7** to your required vaping topography. By default, these are 5, 3 s puffs every 30 s at 18.3 ml/s. Then press upload **S8**. If the required libraries are installed, the code is error free and the Arduino is plugged in the updated program will upload to the Arduino UNO.

The software is configured to allow readings to be recorded for validation purposes. In order to record readings, the ECAM should be set up as described in Section 6.1 and the USB A cable must be connected to a computer throughout the test. The Arduino UNO is programmed to automatically be powered from the 12 V DC power socket while the USB is plugged in and uses this port only for serial communication. Open the serial monitor S9, turn the power on at the wall, and allow the test to run. Once the test has completed, if the temperature and humidity are within range, the flow rate and pump voltage data can be copied into another program to be analysed. Note, that the temperature and humidity measurements are for the external environment. These are not controlled but are recorded to ensure they are within the range specified in the ISO standard.

6.1.4. Testing

To operate the ECAM, plug the 24 V DC power supply (A.PW1) into a 240 V AC Mains wall socket, make sure the power is switched off at the wall. Plug the power supply into the DC power socket on the ECAM. Turn EC on by pressing the side button five times in quick succession. To begin testing, turn the power on at the wall. ECAM will first run the calibration stage, during this period the pump speed is adjusted to compensate for changes in pressure in the system. The LCD will update every 200 ms with the pump signal voltage (out of 5 V) and the corresponding flow rate in ml/s (Fig. 4A). Once the pump has a maintained constant flow rate of 18.3 ± 0.9 ml/s for 3 s, the pump will turn off and, for one second, the LCD will show that the pump has been able to compensate for any pressure changes to produce a steady flow (Fig. 4B). The test will then commence with the vaping topography specified in the Arduino software IDE; the EC state and flow rate is read and displayed on the LCD 5 times per second. When the machine is in the puff phase of the period the LCD will display "EC State: HIGH" (Fig. 4C) and otherwise "EC State: LOW" (Fig. 4D) with the flow rate in ml/s displayed beneath. The system will then run a clearing puff (Fig. 4E). When the test has completed, the LCD will display the average temperature and humidity and the maximum variation accurate to the first decimal place recorded throughout the calibration and test period (Fig. 4F). The LCD will indicate a pass if the temperature is within 15 °C − 25 °C ± 2 °C, and the humidity is 40–70% RH ± 5% RH as specified by ISO 20768:2018 section 5.8 [15].

6.1.5. Post testing

When the test has completed, turn the ECAM off at the wall. Then turn the EC off by pressing the side button five times in quick succession. Remove the needles from the vial cap, the silicone lid will self-seal to retain any compounds that may be present that are volatile at room temperature. Remove the vial from the cold-water bath. The sample is now ready to be analysed or stored. To stop the test at any time, turn the power off at the wall.

Fig. 3. Annotated Arduino IDE. Note, puff duration and period are coded in milliseconds.
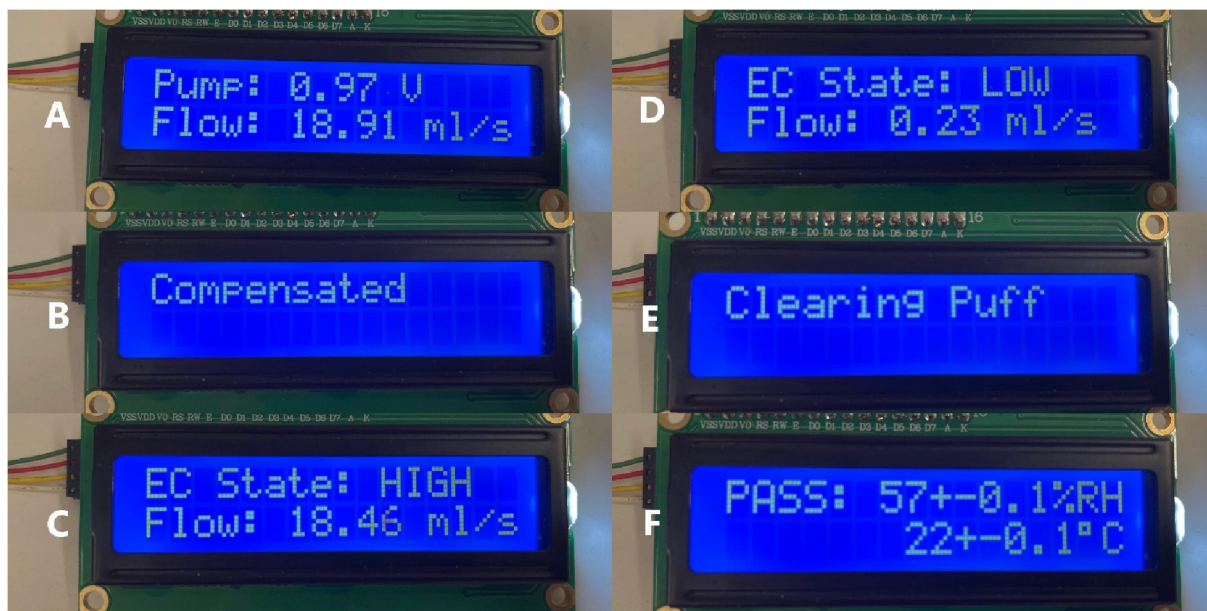
Fig. 4. LCD screen during the stages of the ECAM preparation and testing cycle.

The machine should be cleaned between tests to avoid contamination between samples. This can be done by removing the silicone tube from the mouthpiece of the EC, solenoids, and luer fittings and removing the luer fittings from the needles. Rinse these components with warm soapy water, allow to dry, then disinfect with ethanol, methanol or isopropanol.

6.2. Maintenance

These silicone tube, nylon fittings, luer fittings and needles should be reused between tests. However, the nicotine and flavorings in EC fluids can cause discoloration of the silicone. It is recommended that the tubes/fittings are replaced when this occurs to prevent degradation of the materials which could result in chemical contamination or produce small leaks in the system.

The EC cartridge should be cleaned between testing different EC liquids and the coil replaced. This can be done by unscrewing the cartridge and taking apart the mouthpiece, top cap, glass tube, coil and atomiser base and washing with warm soapy water, then disinfecting with isopropyl alcohol. This will prevent contamination between EC fluid samples.

6.3. Pressure compensation calibration

The ECAM needs to be able to compensate for a 3000 Pa pressure drop without loss of greater than 3 ml puff volume. The steps to test the machine's ability to compensate for this pressure drop are outlined in The Build Instructions Section 28. These describe the changes to the tubes and needles and electrical connections required to measure the pressure. ECAM runs an automated calibration stage at the beginning of every test to account for any pressure variations which can be brought about by changing the type of EC, silicone tube length or needle gauge or length ensuring a flow rate of 18.3 ml/s is achieved for every puff. The flow rate is sent to the serial monitor throughout the test. These data can be analysed as described in Section 28 of the build instructions to determine the ability of the system to meet the pressure compensation requirements outlined in ISO 20678:2018 [15].

7. Validation and characterisation

7.1. Standard puff

Section 4.5 of ISO 20768:2018 [15] requires the puff profile be of a rectangular shape, with a flow rate of between 16.5 ml/ s and 20.1 ml/s when there is a pressure drop device of 1000 Pa ± 50 Pa. The volume of the increasing and decreasing parts of the profile must be less than 10% of the total puff volume, calculated as the area under the flow graph. Fig. 5 demonstrates the ECAM generating a standard puff of 3 s with a pressure drop device of between 958 Pa and 1047 Pa when set to ISO 20768:2018 standard puff conditions (3 s puff duration, 30 s puff period, 55 ml puff volume [15]) using the Lawless Ricky R200 vape and 0 mg nicotine Vanilla Cupcake flavored Aotearoa E-juice. The combined volume of the increasing and decreas-

ing parts of the profile (which must be less than 10% of the total volume as defined by the ISO standards) sum to 3.6 ml. This equates to 6.6% of the total 54.4 ml, thus meeting the standard conditions specified by the ISO 20768:2018.

7.2. Pressure calibration

Section 5.3.3 of ISO 20768:2018 requires that the machine be capable of sufficient compensation i.e. can maintain a consistent puff volume and profile if the pressure of the system changes [15]. This can be quantified by showing a reduction of no more than 3 ml out of the 55 ml puff when the system is tested with a pressure drop device of 3 kPa when initially set with no pressure drop device. To do this, the ECAM automatically runs a calibration stage before beginning each test to determine the pump signal required to counter pressure changes and produce a steady flow rate of 18.3 ml/s given the puff is 3 s in duration. ECAM operates with a 1.02 V pump signal to produce 18.3 ml/s flow rate with no pressure drop device (Fig. 5). When a 3 kPa pressure drop device is introduced to the system (Fig. 6A), the pump signal increases until flow rate is within bounds of 16.5 ml/s and 20.1 ml/s (Fig. 6B). While flow remains within bounds, the signal does not change. When the signal has remained constant for 3 s, the pump is turned off and the signal value is saved to use for the puff phase of the subsequent test.

7.3. Efficiency of collection

ISO 20678:2018 specifies that the efficiency of aerosol collection must be characterised for the ECAM [15]. This can be determined by first measuring the mass of the EC with a full cartridge, and the mass of an empty vial, then running a test consisting of 5 puffs and measuring the change in mass of the EC and vial. To reduce error, 5 tests of 5 puffs should be completed, measuring the change in mass of the EC and vial between each test. The average change in mass can then be determined and the efficiency calculated by dividing the average increase in mass of the vial by the average decrease in mass from the EC. Under standard puff conditions, one 3 s puff every 30 s with a maximum flow rate of 18.3 ml/s, the efficiency of aerosol collection across 25 puffs was 33.94% (SD 6.44%). This value is comparable to another study that recorded an average recovery of vapour of 40% [17]. The ISO standard for vaping devices does not define an efficiency criterion, however it does require that the efficiency is measured and stated.
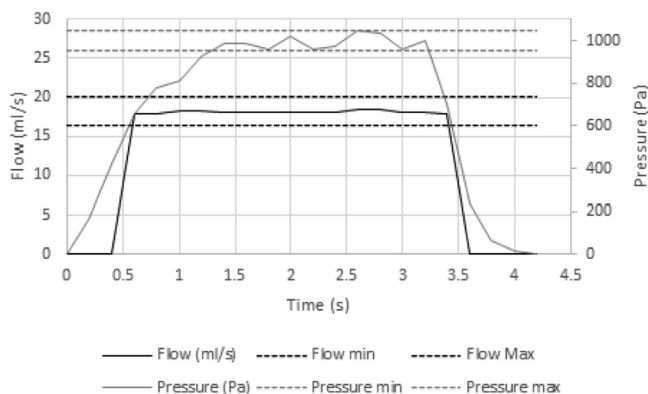

Fig. 5. Flow and pressure profile during a standard test of a 3 s puff with a pressure drop device of 1000 +- 50 Pa.
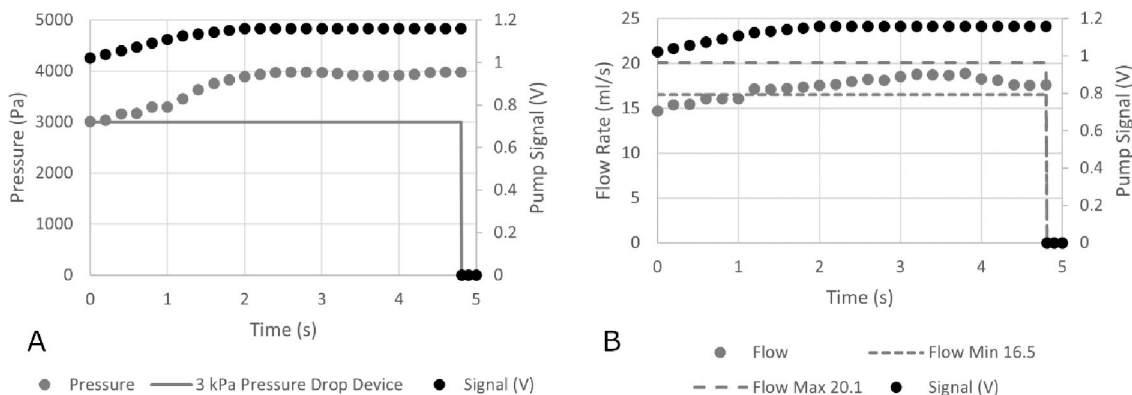

Fig. 6. A: Change in pressure as the pump signal increases to compensate for 3 kPa pressure drop device to produce flow within range. B: Change in flow rate as the pump signal increases to compensate for a 3 kPa pressure drop. Data for both graphs was recorded simultaneously.

It is likely that most of the remaining vapour condenses within the tubing and connectors. In addition, some vapour may also pass all the way through the vaping device. The use of a dry ice/ethanol slurry around the condensing vial may increase the efficiency by a small amount. Efficiency could also be improved by insulating, heating, or shortening the silicone tubes to minimise condensation on the tube walls.

CRediT authorship contribution statement

R.T. Campbell: Methodology, Software, Validation, Formal analysis, Writing – original draft, Visualization. **V. Suresh:** Conceptualisation, Supervision, Project administration, Funding acquisition, Writing - review & editing, Resources. **K.S. Burrowes:** Conceptualisation, Supervision, Project administration, Funding acquisition, Writing - review & editing, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
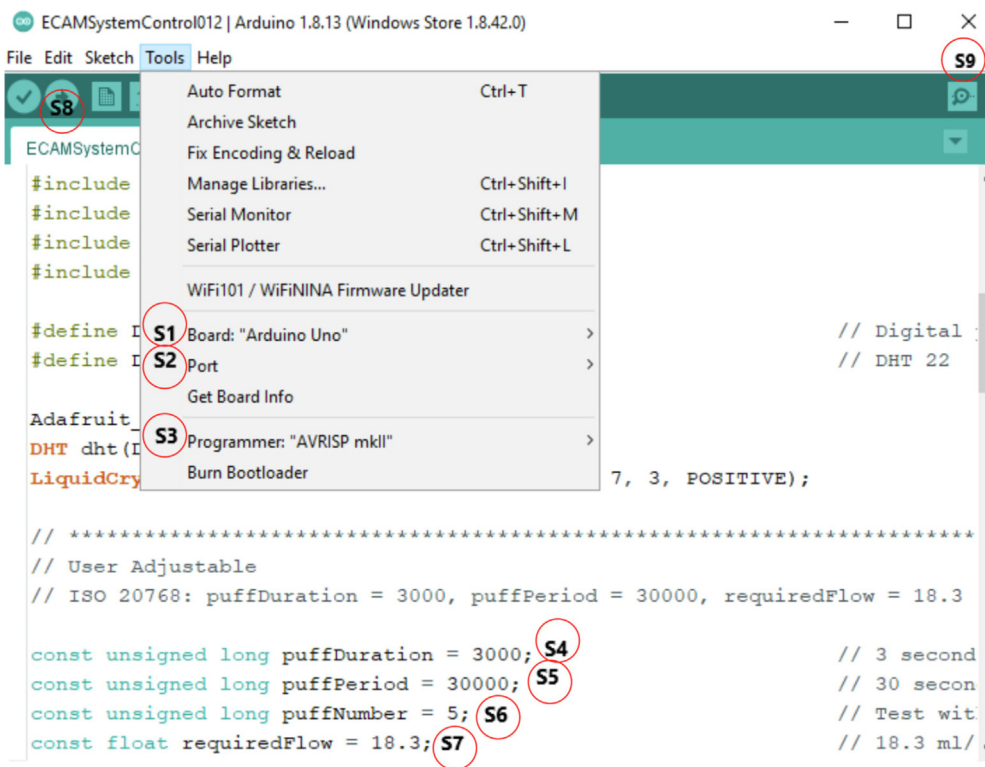
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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.17605/OSF.IO/3NGU4.

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