**SOP for Dekati® eDiluter™ in a wood stove stack with the Höntzsch vane anemometer**
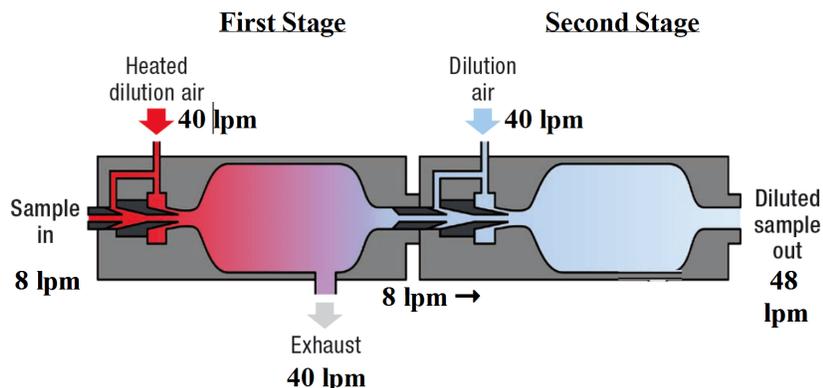
Version DRAFT    May 11, 2020        G. Allen, NESCAUM

This stack PM measurement method is for measuring PM emission rates in a wood stove stack, and covers the dilution and measurement of the stack flow, not the measurement of the PM from the outlet of the diluter.    PM concentration from the dilutor is measured with an EPA Method 5G or ASTM E-2515 filter and with a Thermo model 1405 TEOM.    Operation of those methods is not covered in this SOP.    Note that while sampling proportionality with stack flow is not needed for TEOM PM data, it is needed for the filter pull sample if those data will be used directly to measure PM emission rates instead of only as QC for the TEOM PM concentration data.    In this case, the filter pull PM emission rate can still be compared with the average Dekati-Teom emission rate, but run average PM concentrations can not be compared, since the Dekati-Teom must be at a fixed sample flow for the duration of the run.

Dilution is done with a Dekati eDiluter, and stack flow with a Höntzsch model ZS25/25-350GE/500/p10/ZG4 vane anemometer.    Details on these two products are at
https://www.dekati.com/products/ediluter/
and
https://www.hoentzsch.com/en/products/detail/p/1-sonde-zs25-zg4/

The Dekati eDiluter dilutes the stack aerosol stream by a dilution factor (DF) of approximately 36 with particle free dry air.    It uses two ejector diluters in series, each with a DF of 6 as shown in the diagram below.    The first stage is heated to prevent condensation of water.    The second stage is unheated to allow the sample air to cool.    The outlet stream is near room temperature and very dry.    The only connection needed for diluter operation is pressurized dry air (80 lpm at 60 psi), supplied from a membrane dryer fed by a pair of piston compressor pumps in parallel. The diluter power requirement is approximately 5 amps.    The outlet flow of the diluter is approximately 48 lpm, sufficient to provide samples to several PM measurement instruments. The eDiluter manual (version 1.3) is at https://tinyurl.com/eDiluterV1-3

Dekati eDiluter generic flows for Dilution Factor of 36 (6 x 6)
each stage DF = inlet flow / (inlet + dilution flow)
8 / (8 + 40)

The Höntzsch vane anemometer is inserted into the centerline of the stack sufficiently downstream of any obstructions (typically several duct diameters, and downstream from the PM sampling point), consistent with EPA Method 1A.   It is sensitive enough to measure flows even at low stove air settings.   The anemometer manual is at https://www.omi.co.th/image/2012422897388manual_hoentzsch_UFA-UVA-U329.pdf

For a 6" diameter stack, the proportion of probe obstruction area to stack area is 10%; this is corrected for in data processing.   Since linearity is degraded at flows below 1 m/s, and the range of interest is 0.4 to 2 m/s, the reported velocity is corrected based on the most recent calibration data for flows of 2 m/s and lower using a second-order curve fit.   This stack flow method does not correct for stack water vapor; this would reduce reported flow and thus reported g/h emission rates by approximately 10%.

eDiluter Setup.

This setup assumes the stove under test is not on a scale used for determining burn rate; if it is, then care must be taken to isolate the diluter probe from touching the stack wall to avoid changing the scale's weight.   The diluter must be positioned flush up against the stove pipe. The inlet probe is 8 mm (0.32 inches) diameter, and is inserted so the probe inlet holes that span 1.75" length are centered in the stack.   Any inlet tubing length that is outside of the stack must be insulated.

The dilution air system uses a Dekati DI-1032 membrane drying system.   It is fed pressurized air from two pumps per diluter (Thomas 2685PE40-PLG piston compressors) in parallel, with a 17 foot cooling loop for each pump followed by a water trap upstream of the dryer to remove excess liquid water.   One dryer can be used for two eDiluters if four pumps are used.   The pump system pressure must be at least 4 bar (59 psi) for proper operation of the diluter with a DF of 36.

The outlet of the pressurized air drying system connects to the eDiluter.   Other than the sample inlet, no other connections are needed.   The eDiluter can be controlled remotely using a serial port connected to a computer.   This allows operating temperatures and inlet pressure to be logged, as well as remote control of the diluter operating parameters.

eDiluter Operation.

The eDiluter must be cleaned with acetone in a sonicator before every test run, regardless of the DF measured with CO (see below).   The eDiluter operation is controlled from the diluter's screen as shown in the eDiluter manual.   Operation can also be controlled remotely using the serial port over USB connection, which also logs eDiluter operating mode, inlet pressure, and dilution air temperature.   The eDiluter log file has two time-stamps; the first is the PC time (added by the RealTerm logging system – not the eDiluter), and the second is the eDiluter time which is not accurate.   PC time is always used, so it is not necessary to set the eDiluter time.

The only configuration settings used during normal operation are standby/measurement mode and temperature control of the dilution air.   In standby mode, excess air is introduced at the inlet to create a backwards flow out the dilutor inlet; this also causes the inlet pressure reading to substantially increase (~1500 mb).   Dilution air must be hot enough to prevent condensation in the first dilution stage but not excessively hot to allow the sample air in the second dilution stage to be close to room temperature.   80 degrees C is sufficient.

Daily Operation.

Flow Check.   An eDiluter inlet flow check is done before and after each sample day.   All eDiluter calibration flows reported by Dekati are at 21.1 C and 1013 mb, and are measured with the dilution air heater off (dilution air no more than 2 C above room temperature).   Verify that the pump system pressure is at least 4 bar (59 PSI) in "Measurement" mode.   Measure the flow (nominally 8 lpm) with a TSI model 4140 mass flowmeter (21.1 C and 1 Atm), and record the eDiluter inlet pressure (the first reported pressure in the eDiluter data file) while the flowmeter is connected.   Compare the measured flow to the calibration sheet value using the eDiluter inlet pressure.   The measured flow should be within 10% of the calibration value and ideally within 5%.   This test verifies that the first stage is operating properly, and that the dilution air pressure is sufficient for proper operation (it does not provide any information about proper operation of the second dilution stage).

Standby Mode before start of sample period.   The eDiluter dilution air heater must be turned on at least 5 minutes before sampling from the in-use stack.   The diluter heater will not turn on until the system's pressurized air is turned on.   If the test is not a "cold start", put the eDiluter in "Standby" (flush) mode to prevent stack sampling until the start of the sampling period, and insert the inlet probe into the stack.   Note that pump pressure will be lower in Standby mode, and eDiluter inlet pressure will be much higher.   When sampling begins, put the eDiluter in "Measurement" mode and verify that the pump pressure is at least 59 PSI.   For sampling from a cold start, the eDiluter can be left in Measurement mode after performance tests have been completed.

End of Sampling.   At the end of sampling, remove the eDiluter from the stack, turn the dilution air heater off, let it cool down to within 2 C of room temperature, and repeat the inlet flow check as described above.   To shut the eDiluter down, simply turn off the pressurized air supply. The diluter heater will not run when there is no pressurized air.   The eDiluter can be left powered up in Measurement mode.

eDiluter CO Performance Checks.

The eDiluter DF is verified using 5000 ppm CO supplied to the eDiluter inlet from a cylinder and measuring the CO in the outlet of the diluter. This is done in measurement mode with the dilution air heat turned off before a test run and at the conclusion of the test run.   The measured DF is the cylinder concentration divided by the CO measured from the diluter.   No correction for room CO is needed, since the diluter CO will be approximately 150 ppm.   The target DF is taken from the eDiluter calibration sheet lookup table, adjusted for the eDiluter inlet pressure

read from the eDiluter while doing this test.

The average of the pre- and post-test ratios of stack to diluter outlet CO is the actual DF for use in calculating stack PM from Teom data.    If the measured DF is more than 10% from the calibration value for the pre-run test, the eDiluter must be cleaned again per the instructions in the eDiluter manual.    If the post-run measured DF is more than 10% from the calibration value, the test results should be flagged.

If the eDiluter CO check fails (> 10% from target value), the performance of each stage can be assessed separately by also measuring the CO out the side port of the diluter (the exhaust of the first stage).    This gives the DF for the first stage.    The DF for the second stage is the ratio of the first stage exhaust CO to the outlet CO concentration.    For the side port measurement to be valid, the CO analyzer must be calibrated over the full range of interest.

Diluter Cleaning.

After every test run, the two ejector diluters are removed from the eDiluter and cleaned with acetone in a sonicater for 10 minutes.    A cleaning brush supplied with the eDiluter is used to mechanically clean the ejector nozzles.    The post-cleaning DF should be checked with CO before the eDiluter is used.

Additional troubleshooting information:
The orifices that control the dilution flows for the two stages are built into the ejector diluter assemblies.    While the eDiluter inlet flow check confirms that the first diluter stage is working properly, and cleaning the ejector nozzle of the second diluter stage with the supplied nozzle cleaning brush will insure it is not blocked, flow diagnostics for the second stage diluter can only be checked by disassembling the second stage and measuring the ejector nozzle flow for comparison to the calibration value, using a pressure correction similar to that from the eDiluter's calibration sheet.    If needed, the 2nd stage dilution flow can be measured by blocking the ejector nozzle and measuring the outlet flow (~ 40 lpm) from the second stage for comparison with the calibration value.    These measurements are necessary only as a troubleshooting procedure, not for normal operation.

A quick indirect check of the second stage diluter inlet flow for diagnostic use only can be performed as follows.
First measure the outlet flow from first stage exhaust port during normal operation with a 50 or 100 slpm mass flowmeter; this is a quick additional check on stage 1.    Then disconnect the quick connect for the second stage dilution air, and block it; this stops the second stage inlet flow.    Then block the 2nd stage outlets (the 3 ports).    The increase in first stage exhaust flow gives you the 2nd stage inlet flow by difference for comparison with the Dekati calibration flows.

Note: second stage ejector diluter flows are not normally reported with the eDiluter calibration sheet, but are available on request to Dekati support.

eDiluter Rinse for Measurement of Catch.

For the first set of six pellet stove runs, the eDiluter catch will be measured after each day's run to determine if this is necessary for all runs.   The inside surfaces of the two eDiluter sections and inlet probe are rinsed with acetone, using the same approach as is done for collecting probe catch.   The acetone is then evaporated and the remaining material is weighed.   This is the eDiluter "catch" [the mass of PM retained by the eDiluter].   This total PM catch mass can not be added directly to the mass collected on the sample filter, since only a small portion of the total eDiluter air flow goes into the filter.   The total mass of PM passing through the eDiluter is calculated for each section from the flows through the eDiluter (eDiluter flows are steady-state, nominally 48 lpm in each stage), the estimated concentrations in that flow (from Teom or filter PM concentration data), and the duration of the diluter operation when sampling from the stack (the same duration as the filter pull).   The average PM concentration for the first eDiluter section is the average PM concentration measured by the filter or Teom multiplied by the DF of 6.   For the second eDiluter section, it is simply the average PM concentration measured by the Teom or filter.   These two mass amounts are added to get the total mass of PM that passed through the dilutor.   The eDiluter PM loss (expressed as a fraction of sampled PM) is the measured catch divided by the total mass of PM that passed through the dilutor.   The measured filter and/or Teom mass can be corrected for PM loss in the eDiluter using this value.   Note that to properly correct for eDiluter catch, the eDiluter should be sampling from the stack only when a filter sample is being pulled.   There is only one eDiluter catch rinse each test day; if multiple filter pulls are performed in a single day, the dilutor catch is apportioned between them based on the sample run times.

Filter Pulls.

As a performance check on the Teom and diluter combination for stack PM emissions, a manual filter pull will be done for each test run for comparison with Teom PM from matching time periods.   Thus both eDiluter and Teom performance are independently verified.   If the filter pull is used only to validate the TEOM run-average PM concentration from the diluter then filter pull proportionality with stack flow is not needed.   However, if the filter pull PM is the primary PM measurement for the run, then the filter flow will need to be varied proportionally with the stack flow corrected to standard conditions.   If this is done, then the filter pull and TEOM data can only be compared using run-average grams per hour data.   For these tests, the 5G filter pull will be proportional, and comparison of those data with the run average emission rate will be used for a performance check of the Dekati-Teom measurement system.   For the purposes of this comparison, anemometer stack flows are used for both systems.

Vane Anemometer Operation.

The anemometer must be inserted into the stack so that the sensor is at the center-line, at least 8 duct diameters from any bend or diameter change in the stack. Consistent with EPA Method 17 section 8.1.2 and EPA Method 201A section 10.4, the anemometer stack location is separate from the PM sample probe stack location.   It is critical that the sensor be rotated so the

anemometer is facing the flow direction and the dot on the sensor noting the forward flow direction (at calibration) **is facing into the flow** (toward the stove).    The base of the sensor can be used to check this alignment.    There are two connections to the anemometer: one for power from a small wall unit, and the other for serial port data that connects to a PC.

The sensor comes with "UCom" software to set configuration and to record the flow data:

Plug the sensor into a USB port on the PC.
Open the Höntzsch UCom program from its icon.
From the top menu: "connect automatically", then "resume" to connect.
From the top menu: "read data".    This loads the instrument config from sensor.
        (Do NOT change the config settings)
Verify that configuration settings are as listed in Appendix A.
The time constant can be changed to be equal to the data acquisition interval.
Set the UCom measuring interval to 60 seconds for 1-minute data acquisition
Select "Record", click OK twice to start.

**IMPORTANT NOTE:** The measuring interval MUST be set to > 0 for the UCom display to read realtime data.    It doesn't need to be saving, but the interval must be > 0.    To read / write stored parameters, the interval must = 0.

The data file has the start date and time in the file name, and velocity in m/s at stack T and P. The file format is flat ascii, with PC timestamp for each data record.    The sensor configuration is in Appendix A, or as supplied by the manufacturer with each instrument.

A type K thermocouple is used to measure stack temperature once per minute just downstream of the anemometer.    Room barometric pressure is measured at the start and end of each test day, and can also be obtained from the eDiluter log file 1-second measurements (the second of the two pressure readings).

If needed, stack velocity traverses can be done to measure any reduction in flow near the stack wall.    For a 6 inch diameter stack, a single measurement one inch from the stack wall is sufficient for comparison with the flow measured at the center of the stack.

Cleaning of the anemometer should be done at least weekly (daily for dirty burn runs), using an ammonia soak overnight followed by a gentle water rinse to remove solid material loosened by the ammonia soak and blow-dry.    For this routine cleaning, **Do NOT use an ultrasonic bath, and do NOT use acetone!**    After cleaning, blow through the vane wheel from both sides with a hair-dryer (per the manual, this is for the self-cleaning effect of axle tips and bearings).    Then verify that any soot coating on the propeller vanes and axle has been removed, since any remaining coating could interfere with the aerodynamics of the fan blades and cause reading errors.

For stoves with high PM emission rates, the ammonia cleaning may not remove all of the deposits from the anemometer fan blades.    If this happens, remove the anemometer vane ring from the probe by taking out the small screw that holds the vane ring in place.    Soak the vane

ring in acetone and then gently rinse with water.    Verify that there are no more deposits on the fan blades.

**Note:** The anemometer blades are fragile – cleaning techniques need to be mechanically gentile.

Anemometer QC checks include observing the real-time flow data for stability during the test run (flow should never go below 0.35 m/s at stack T), and that both before and after (and during as needed) the test run the vane turns freely when the probe is moved in room air at ~ ½ m/s. Calibration over the range of 0.4 to 5 m/s is done by a certified laboratory at the start and end of the project and at least annually.    The manufacturer does not do any calibration points below 1 m/s, which is not low enough for most wood stoves.

Performance Check.
A quick performance check of the anemometer can be performed by verifying the reported starting speed.    Use a large window fan at the lowest speed setting to create an airflow field. Set the anemometer time constant to 1 second, and the recording interval to 1 second.    With the sensor about 10 feet feet from the fan, move the anemometer in and out of the flow field slowly to determine the minimum reported velocity it can measure.    This should be no higher than 0.35 m/s, and typically 0.31 or 0.32 m/s.    If the anemometer passes this check, velocity data should be close to the calibrated values.    If it fails, repeat the cleaning.    In addition to ammonia, isopropanol can also be used as a cleaning solution (separately, not a mix of both).

Data Reduction.

All continuous data are averaged up to 1-minute duration prior to data processing.    Raw stack velocity data are corrected using a second-order calibration curve based on the most recent calibration data.    Consistent with EPA Method 17 section 8.1.2 and EPA Method 201A section 10.4, stack velocity is then corrected for the cross-sectional blockage area of the anemometer, approximately 10% for the probe in a 6" stack centerline per "Stack Sampling Technical Information: A Collection of Monographs and Papers (Volume II)", EPA-450/2-78-042b. From Table VI of that publication, for blockages between 7.9 and 10.8%, the following equation is used to estimate the blockage velocity correction factor from the actual %blockage value:

Velocity Correction Factor = 22.63 + -5.688 * %blockage + 0.447*%blockage^2

Note: This stack flow method does not correct for stack water vapor; this would reduce reported flow and thus reported g/h emission rates by approximately 10%.

The corrected stack flow in m/s at stack temperature and pressure is converted to stack flow in cubic meters per minute at STP (25 C and 1 ATM.) using the stack diameter, temperature, and pressure and the equations in EPA Method 2D, "Measurement of Gas Volume Flow rates in Small Pipes and Ducts".    A spreadsheet with calculations for raw stack velocity to STP flow is used to get flow in cubic meters and cubic feet per minute at STP, corrected using the anemometer calibration curve and corrected probe blockage area (1).    STP stack flow in cubic meters per minute is then multiplied by PM concentration in grams per cubic meter to get PM emission rate in grams per minute.    Multiply that by 60 to get grams per hour at 1-minute

intervals.   The average of all 1-minute PM emission rate measurements is the run-average grams per hour value.

Note:   Proportionality with stack flow is not needed for PM emission rates from Teom PM data, since all of the data (stack flow, stack temperature and pressure, and PM concentration) are processed into PM emission rates using 1-minute data.   The filter pull will be done with proportionality using the anemometer stack velocity data, and thus the Dekati-Teom PM data can only be compared to the filter pull data on a grams/hour basis, not a PM concentration.

(1) Stack flow calculation spreadsheet "Anemometer stack flow calcs.xlsx" is incorporated into this document.

Appendix A: Höntzsch vane anemometer configuration.

These settings are saved in the instrument, and retrieved by the instrument software on startup.
**Do not change any of them.**

Parameter Settings As Factory Calibrated. (UFA mn20 13393 500·c, 0 to 20 m/s)
date: 26.04.2018      time: 07:40:03
device version: UFA 26

Software Configuration, Screen 1:
Parameter set list no.  ...................................00100

Serial no. .....................................................13393

Terminal value - analog output ......................20.00 m/s

Profile factor PF............................................1.000

Pipe inside diameter .....................................100.0 mm (not used)

Time constant...............................................00001 s (set to 60 s for 1-minute data acquisition)

Sensor type...................................................00001 (mn FA)

Measuring range FA .....................................00000 (20 m/s – **critical setting**)


Software Configuration, Screen 2:
Medium FA...................................................00000 (gas)

Directional sensing FA .................................00000 (without directional sensing)

switching pulse / limit value / FAR ...............00001 (limit value velocity)

Limit value v ................................................40.00 m/s (not used)

Switching pulse m3 (cbm) / 1 (litre)..............00000 (not used)

m3 (cbm) / 1 (litre) per pulse ........................00001 (not used)

Pulse configuration +/-..................................00000 (not used)

Decimal places quantity display ....................00000 (not used)


Software Configuration, Screen 3:
Switching v / Nv ...........................................00000 (actual velocity, t/p settings not used)

Actual pressure (absolute).............................1013 hPa (not used)

Actual temperature........................................273.2 K (not used)

Standard pressure (absolute).........................1013 hPa (not used)

Standard temperature .....................................273.2 K (not used)