BRECHTEL

TAP

TRICOLOR ABSORPTION PHOTOMETER

MODEL 2901 SYSTEM MANUAL

BMI PN 003100024 Rev 10

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1 Unpacking

Each TAP receives thorough testing and inspection at the factory to ensure your instrument is ready for operation when you receive it. Inspect the packaging before opening. If the packaging is damaged and/or the shock watch has been tripped, contact and notify the shipping company immediately.

If the packaging does not show signs of damage, after carefully opening, inspect the instrument for broken parts, scratches, dents or other signs of damage incurred during shipping. **Notify BMI within 2 days of receiving package if ShockWatch has been tripped.**

Verify the contents of the shipment with the unpacking instructions, which are included both with the instrument and as a separate .pdf. **Retain all shipping packaging, foam inserts and cushions to ensure a safe delivery should the instrument need to be returned.**

Figure 1: Shock Watch

2 TAP Overview

The TAP has been designed in a small and light form factor with an easy to change filter. The flow rate is displayed via the front mounted display and can be adjusted with the flow needle valve as required. The TAP differs from the single spot absorption photometers in that it utilizes 10 solenoid valves to cycle through 8 sample filter spots and 2 reference filter spots. As shown in the flow schematic, the sample enters the barbed fitting in the rear of the unit and passes first through the sample spot of the 47 mm filter. The same LED light source simultaneously shines light through the current sample and reference spots. Each of the 8 sample spots is separated from the other by O-rings that clamp the filter material to prevent any inter-spot leakage. The air flow passes through the filter and into a solenoid valve controlled by the TAP Reader software. The flow exits the sample solenoid valve and is routed to one of two reference spots in the same 47 mm filter used for the sample spots. Since no particles remain in the flow at this point, the reference spots allow changes in light transmission due to filter, flow or other changes to be monitored in real time. More importantly, the reference spot allows a differential measurement approach in the TAP so the increase in light attenuation due to deposited particles on the sample spot can be largely separated from filter effects. Each time the sample spot is changed the reference channel is also changed. The flow passes through the reference spot and into another solenoid valve, exiting the valve the flow enters the internal flow meter. The needle valve is located downstream of the flow meter, with the vacuum connection on the rear panel directly connected internally to the outlet of the needle valve.

The TAP uses 47-mm diameter, glass-fiber filters (Brechtel TAP-FIL100). These filters are made of two fibrous layers, borosilicate glass fibers overlaying a cellulose fiber backing material (for strength and stability). The cellulose fiber layer is thought to take up water under conditions of high humidity, which is one reason the TAP has an internal heater to decrease the risk of condensation within the instrument.

The red indicator lamp on the front of the TAP is off during normal sampling and on during a filter change. A blinking lamp indicates an error condition that must be corrected before continuing.

The TAP requires an external computer for data logging and instrument control. The internal software in the TAP provides the minimum functionality for measuring signals (light intensity reaching the ten detectors, flow rate, case temperature, and sample temperature) and controlling the hardware (light source, case heater, and solenoid valves). The internal software detects when the pushbutton on the front panel is depressed and controls whether the red indicator lamp is lit or not.

IMPORTANT NOTE*:* Beginning in March 2016, Pall Corporation discontinued production of the glass fiber filters used in the TAP. After this date the only valid filter material selection in the TAP Reader software is 'Azumi M371'. A preliminary filter loading correction is implemented in the TAP Reader software (version 2.6 and higher). A final version of the correction will be implemented as soon as possible.

When combined with the TAP Graphical User Interface Software, the TAP reports the change in light transmission through the filter. The TAP provides 8 automatically changing filter sample spots to provide the user with increased sample time between filter changes. All data collected is saved and displayed in real time for analysis. Software communication

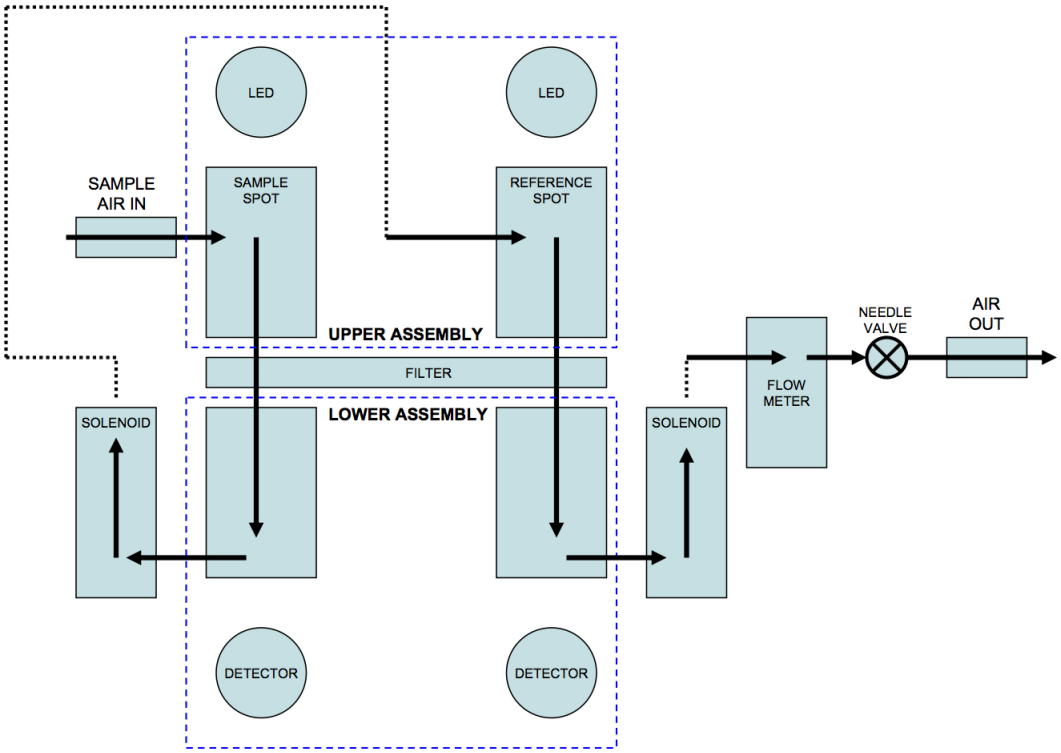

Figure 2: Schematic of the sample air flow within the TAP.

to the TAP is established through the COMM Out port on the back of the instrument using the RS-232 protocol.

3 Theory of Operation

3.1 Introduction

Light absorption in a medium can be quantitatively described using the Beer-Lambert Law

$$I = I_0 e^{-\sigma[\lambda]l}, \tag{1}$$

where I and I_0 are the output and input intensity of light in Watts per square meter passing through an absorbing medium, σ is the medium's attenuation coefficient in inverse meters at wavelength λ in meters, and l is the path length in meters through the medium. This is demonstrated qualitatively in figure 3[1] by the attenuation of a green laser through a solution of Rhodamine 6B.

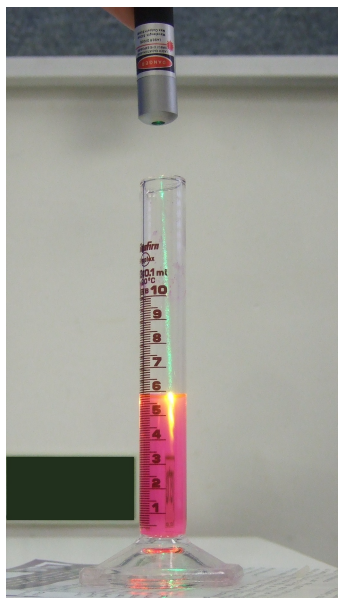

Figure 3: Beer–Lambert law in solution

In order to apply this to a light absorption photometer the critical assumption is made that absorption through a length of air at a given time is equivalent to filtering out the absorbing species from the air on a filter and passing the light through this instead. If this is true, then in a given time period Δt this can be expressed as

$$I(t) = I(t - \Delta t) e^{-\sigma_{PSAP}[\lambda] \frac{Q_{PSAP} \Delta t}{A_{PSAP}}}, \tag{2}$$

where $I(t)$ is the intensity of the light reaching the detector at any given time, $\sigma_{PSAP}[\lambda]$ is the average, wavelength-dependent absorption coefficient of the air parcel that passed through the filter in Δt, A_{PSAP} is the filter area, and Q_{PSAP} is the flow through the filter area. A_{PSAP}, Q_{PSAP}, and Δt define the length of the air parcel passing through the filter

[1] by Amirber - Own work. Licensed under CC BY-SA 3.0 via Commons

area.[2] Unfortunately, this assumption does not take into account the filter material or the properties of the bulk developed in depositing the particles both on and in the filter, but we can define a filter-loading correction factor, $f(\tau)$, determined empirically, to correct for this, resulting in

$$I(t) = I(t - \Delta t)e^{-\sigma_{PSAP}[\lambda]\frac{Q_{PSAP}\Delta t}{A_{PSAP}}\frac{1}{f(\tau)}}. \tag{3}$$

With some minor rearrangement this becomes

$$\sigma_{PSAP}[\lambda] = f(\tau)\frac{A_{PSAP}}{Q_{PSAP}\Delta t}\ln\left(\frac{I(t-\Delta t)}{I(t)}\right), \tag{4}$$

the most basic description of an absorption photometer's operation.

3.2 Absorption Coefficient Correction

The analysis below follows "Comment on 'Calibration and Intercomparison of Filter-Based Measurements of Visible Light Absorption by Aerosols'" by John A. Ogren 2010.

Eqn. 12 in the above work is

$$\sigma_{ap}[\lambda] = 0.85\left(\frac{Q_{PSAP}}{Q_{meas}}\right)\left(\frac{A_{meas}}{A_{PSAP}}\right)\frac{\sigma_{PSAP}[\lambda]}{K_2} - \frac{K_1}{K_2}\sigma_{sp}[\lambda]. \tag{5}$$

Here σ_{ap} is the aerosol absorption coefficient, σ_{sp} is the aerosol scattering coefficient, $K_1 = 0.02 \pm 0.02$ and $K_2 = 1.22 \pm 0.20$ are empirical coefficients defined by the equation

$$0.85\sigma_{PSAP} = K_1\sigma_{sp} + K_2\sigma_{ap}, \tag{6}$$

and Q is the flow[3] through both the experimental and reference channel, and A is the area of each sensor spot. Here $f(\tau) = (1.0796\tau + 0.71)^{-1}$ is the experimentally determined correction function for filter loading, $I(t) = \frac{\langle color-dark\rangle_t}{\langle colorref-darkref\rangle_t}$ is the ratio of the average intensity of one color at the experimental spot to the reference spot over time period Δt, and $\tau = \frac{I(t)}{I_{wf}}$ is the filter transmission[4], and I_{wf} is the intensity ratio measured while doing the white filter check. In our instrument $Q_{PSAP} = Q_{meas}$ and $A_{PSAP} = A_{meas}$, so Eqn. 12 simplifies to

$$\sigma_{ap}[\lambda] = 0.85\frac{\sigma_{PSAP}[\lambda]}{K_2} - \frac{K_1}{K_2}\sigma_{sp}[\lambda]. \tag{7}$$

Depending on the version of software you have, you may have an option to define σ_{sp}. If you don't have this option, then the program actually calculates

$$\sigma_{ap}[\lambda] = 0.85\frac{\sigma_{PSAP}[\lambda]}{K_2} \tag{8}$$

instead.

[2]The PSAP label is used here to match the equations described below for further corrections of the absorption coefficient. This analysis is not unique to the PSAP.

[3]The flow data is corrected for temperature and pressure before being used in the calculation.

[4]To calculate the transmission we use the color ratio from the most recent $\triangle t$, e.g. if you're doing 5 sec averaging make sure to use the color ratio from the current 5 second interval, not the previous 5 second interval, or the full 10 seconds used for each measurement.

3.3 Data Filter

The TAP software allows the user to implement a four stage, single-pole, low pass filter in its Advanced options tab. The filter's arguments are 2.17872e-1, 1.26719, -6.02159e-1, 1.27174e-1, -1.00721e-2, and it has an effective first-order time constant of 2.6 seconds. All raw data recorded by the TAP software does NOT have the filter applied.[5]

3.4 Data Averaging

The TAP software allows the user to set a running, boxcar average. The running average will be composed from the data currently available, until the data series reaches the desired length. For example, if the average is set to 60 seconds, and there are currently 3 seconds of data, the displayed value will be a 3 second average.

[5]The TAPs have a legacy option in their firmware to implement an adjustable low pass filter. This firmware filter was applied to the "raw" data and is disabled in the current software.

4 Installation

4.1 Mounting

The TAP is shipped with 4 rubber feet so that it can be installed on a table top. The feet can also be removed and the TAP can be bolted down with 6-32 screws for non-movable installation (figure 4). Bolts should not extend further than a quarter inch into the cover.

Figure 4: Removable feet

4.2 Connecting plumbing

The 1/8 inch barb fitting on the back of the TAP (figure 5), labeled VAC IN, needs to be connected to a vacuum pump capable of pulling 2 LPM at 9"Hg. **Oscillations and disruptions in the vacuum source may cause the filter to oscillate and affect the measurements**. A suitable pump may have been optionally purchased with the instrument. The sample line should be connected to the SAMPLE IN port. A $\frac{1}{4}$-inch barb is included pre-installed on the instrument, or the underlying 10-32 threads may be used to adapt to other fittings.

4.3 Connecting the power

The included AC adapter has an input voltage of 100-240 Volts ~1 AMP, 50-60 Hertz and an output of 24 Volts at 3 AMP. Replacement AC power cords are available for various wall plug styles. Insert the connector from the AC adapter into the TAP (figure 5) and connect to power source. **Ensure the barrel plug is fully seated in the connector before connecting the instrument to a computer.**

4.4 Connecting to a computer

The TAP may be furnished with an optional tablet, or you may use your own Windows computer to connect to the TAP. The Brechtel control software records, saves, and analyzes data from the instrument. Raw serial communication is also supported. An RS-232 to USB adapter cable is included with the instrument.

1. Plug the serial-to-USB connector into the instrument and the computer (figure 5). **Failure to tighten the thumb screws on the COM cable may result in loss of communication with PC.**

2. Start the TAP control software (see instructions below).

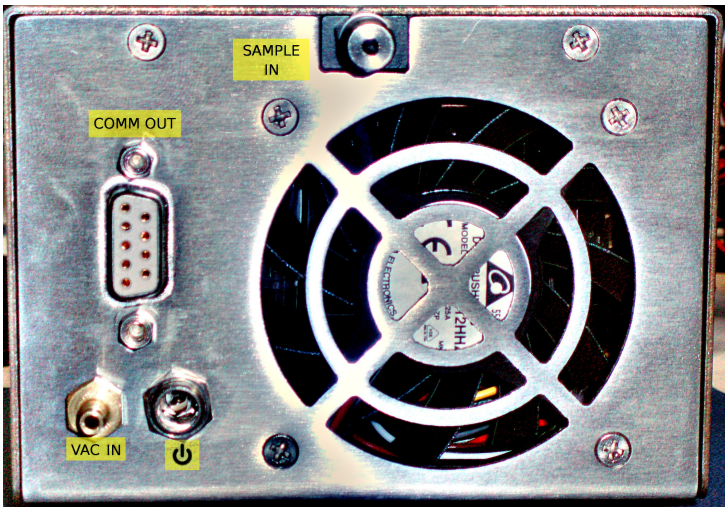

Figure 5: Back of TAP

4.5 Filter Material and Spot Area

As of this writing, only Azumi M371 and Pall E70 and Emfab filters have been characterized to work with the TAP. These options are available in the provided TAP software, which will perform all necessary corrections based on the selected option.

The TAP filter spot area is a function of the filter material in use. It is 2.5281E-5 sq. m for the Azumi filter and 3.0721E-5 sq. m for the available Pall filters.

4.6 Installing a filter

1. Press the red filter change button (figure 6).

Figure 6: Red filter change button

2. Remove the 4 thumb screws from the top of the instrument (figure 7).

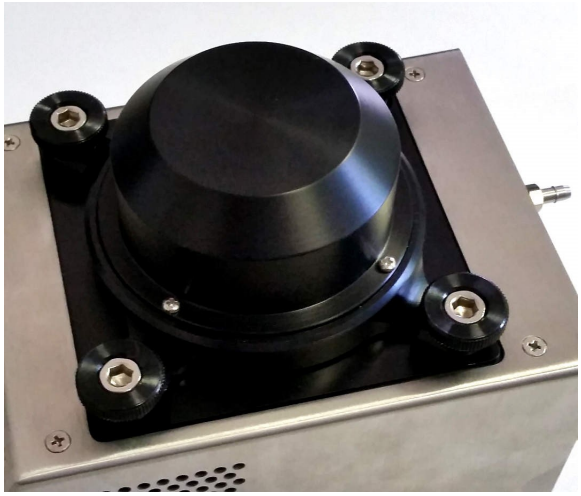

Figure 7: TAP thumb screws

3. Gently remove the upper "top hat" from the instrument body by pulling upwards (figure 8).

Figure 8: TAP top hat removal

4. Remove the old filter. It may be discarded if desired.

5. Clean any filter residue or debris from mating surfaces using a clean ethanol-soaked wipe (figure 9), taking care to prevent debris from falling into the instrument flow path. This is most easily accomplished by holding the unit or top hat such that any debris that falls, falls away from the optical path. If any debris gets into the instrument, gently blow it out with dry filtered air.

Figure 9: Filter debris

6. Verify that all 11 O-rings on the instrument body (figure 10) and all 12 o-rings on the top hat assembly are present (figure 11). Your o-ring color may vary. The numeration on figure 10 and figure 11 refer to the o-rings. They are in no way connected to the experimental or reference spot number as displayed in the GUI or recorded in the data file.

Figure 10: Body o-rings

7. Every 20 filter changes, lightly lubricate the side o-rings, 11 and 12, on the top hat assembly (figure 11).

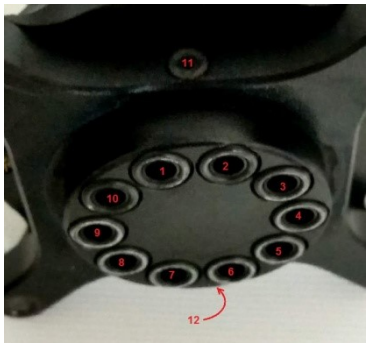

Figure 11: Top hat o-rings

8. Using a set of tweezers, place a new filter into the TAP cavity (figure 13) with the rough white perforated side facing up (figure 12). Make sure only one filter is installed; sometimes two filters stick together.

(a) Face down filter

(b) Face up filter

Figure 12: TAP filter orientation

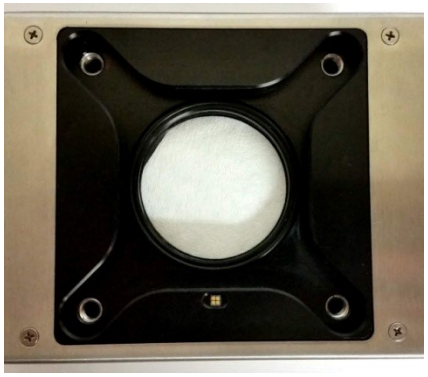

Figure 13: New filter installed

9. Below, figure 14 shows the experimental and reference channels for the TAP instrument, as well as the direction of channel progression. Channel 9 is the reference for all odd spots, and channel 10 is the reference for all even spots.

10. Verify the correct orientation of the top hat before placing it onto the instrument body (figure 15). The two side connectors should line up.

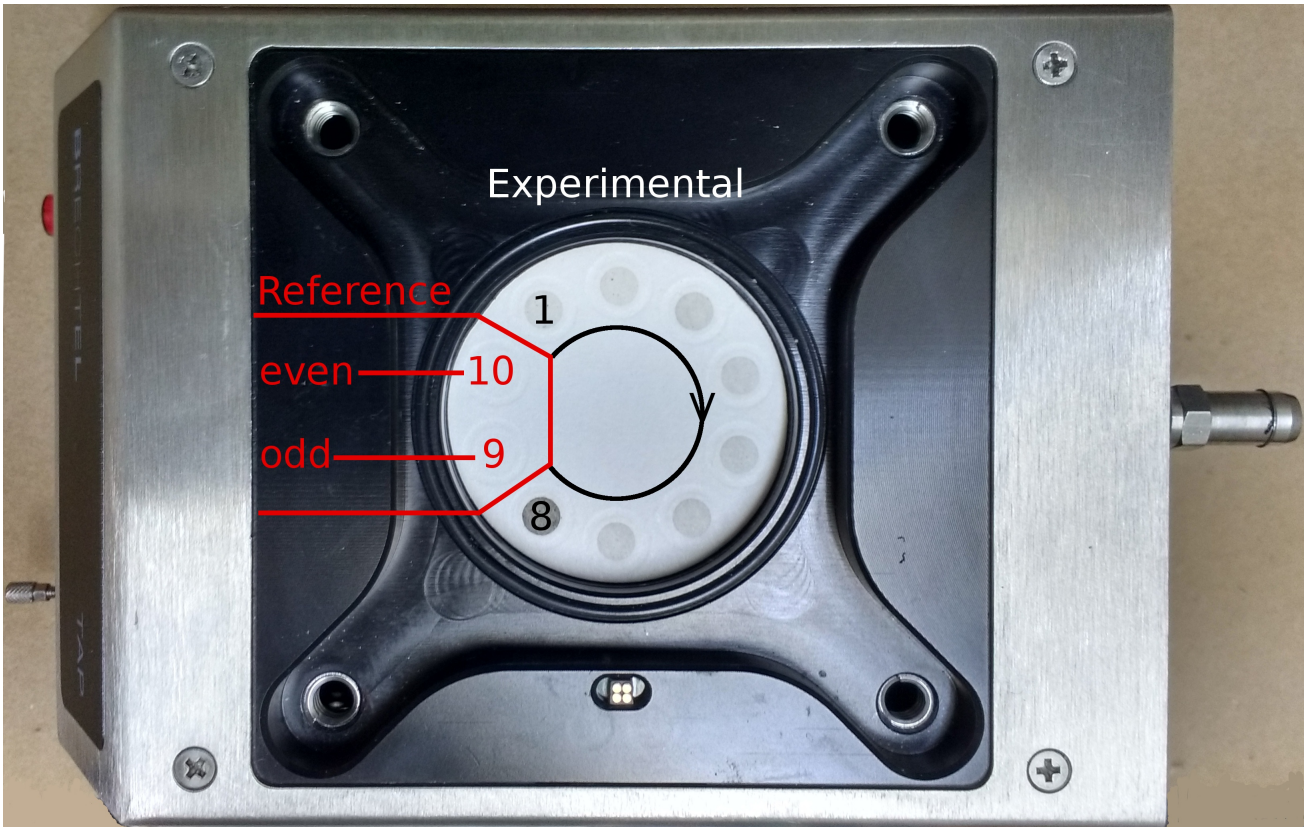

Figure 14: Experimental and reference channels

Figure 15: Top hat orientation

11. Gently seat the top hat in the cavity. Do not force it in. **It is impossible to fully seat the top hat in the cavity if it is in the wrong orientation, and attempting to do so may damage the instrument.** If you encounter difficulty, check the orientation and try again.

12. Once seated, secure the top hat with the 4 thumb screws from figure 7. Tighten them in a star pattern. You should be able to fully engage the threads without tools, but if necessary the thumb screws have sockets for hex keys.

13. Press the red button to signal that the filter change is complete. The red lamp should turn off. **The TAP will not begin sampling automatically after a filter change. The TAP Graphical User Interface Software must issue commands to the TAP to begin sampling.**

14. Once the TAP begins sampling after the filter change, compare the flow rate with the value before the filter change. If the flow rate is significantly different, the top hat may not be fully seated, or you may have accidentally inserted multiple filters.

4.7 White filter check

The white filter check is a baseline measurement of the intensity measured on all ten detectors with a new filter using particle-free air. It is important to establish a baseline range for the instrument.

The TAP must be warmed up for at least 10 minutes before performing a white filter test and before acquiring data. First, ensure that a filter is installed on the input flow. Brechtel has supplied a canister filter for this purpose. Put a new filter in the TAP (see Installing a Filter), start the Brechtel TAP control software, and select START. The TAP GUI will ask if you have a new or old filter. Select "Yes" to automatically begin a white filter check.

The instrument will notify the user when the white filter check is complete, so that the user can remove the filter from the inlet and begin normal sampling. The check normally requires 30-40 minutes.

5 Operation with TAP Graphical User Interface Software

Warning: The TAP GUI turns off the firmware low pass filter and automatically sets the LED power.

1. Launch the BMI TAP Reader software.
2. Correctly set the COM Port on the Main tab.
3. (Optional) Select the Advanced tab and change the configuration as necessary.
4. (Optional) Press "Save current settings" to save the current setting on all tabs as startup settings.
5. Press "START" on the Main tab to run.

5.1 Advanced Tab

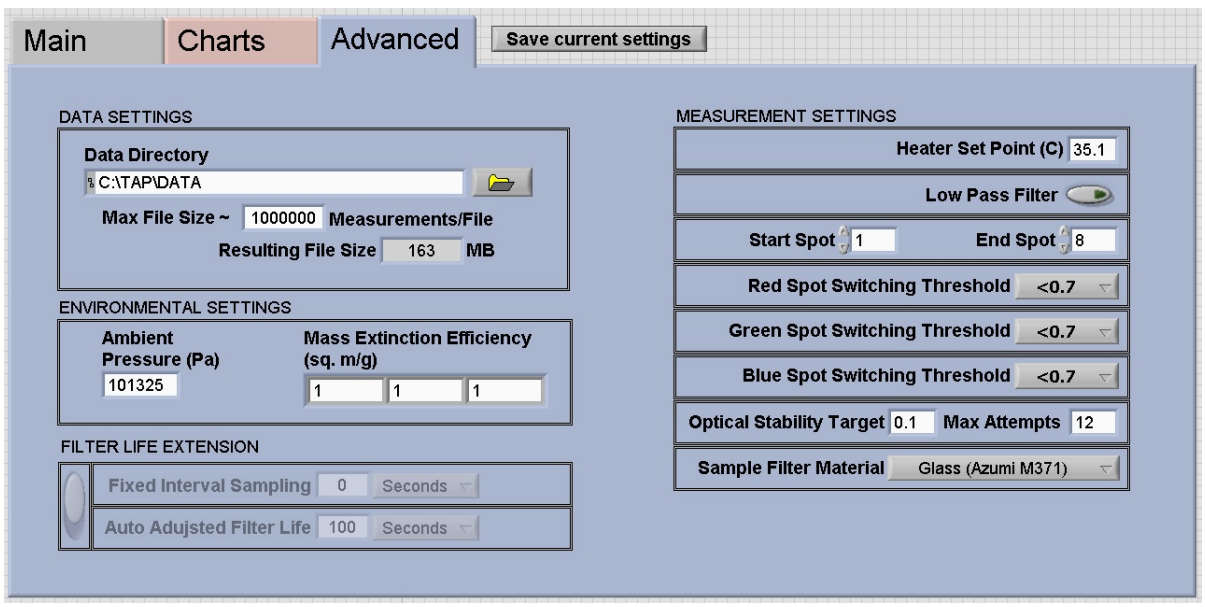

Figure 16: TAP GUI Advanced Configuration Tab

5.1.1 Data Settings

Data Directory	This is the directory where the TAP data will be saved as a .dat file
File Size	The size of the .dat file can be set to an approximate number of measurements with an associated file size. Once the size has been met a new file will be created and saved in the same directory.

5.1.2 Environmental Settings

Mass Extinction Efficiency	Please enter the conversion factor between absorption and extinction efficiency for your soot.
Pressure (Pa)	Set this value according to the atmospheric pressure for which the TAP is installed. This must be manually measured.

5.1.3 Filter Life Extension

Fixed Interval Sampling (disabled)	Set the amount of time that the user wishes to have the unit sit idle between measurements to extend filter life.
Auto Adjusted Filter Life (disabled)	Set the amount of time that the user wishes the filter to last. When this feature is used, the wait between averages will auto adjust to preserve the filter life accordingly.

5.1.4 Measurement Settings

Heater Set Point (C)	Changes the heater set point in the firmware. Changing this setting WILL interrupt data taking.
Low Pass Fillter	This low pass filter is a software-based, 4 stage, single pole filter with effective first-order time constant of 2.6 seconds. Arguments are 2.17872e-1, 1.26719, -6.02159e-1, 1.27174e-1, -1.00721e-2. The firmware low pass filter is turned off.
Start Spot	The first filter spot used by the unit to take measurements.
End Spot	The last filter spot used by the unit to take measurements.
Red/Green/Blue Spot Switching Threshold	The transmission threshold to initiate a channel switch command. The sample channel will be changed as soon as any threshold is crossed.
Optical Stability Target	The maximum relative standard deviation in the reference intensity acceptable for taking data.
Max Counter	The number of tries (of 45 seconds each) that the unit will give the reference channel to see if it stabilizes below the maximum relative standard deviation described above.
Filter Material	Which filter material are you sampling with?

5.2 Charts Tab

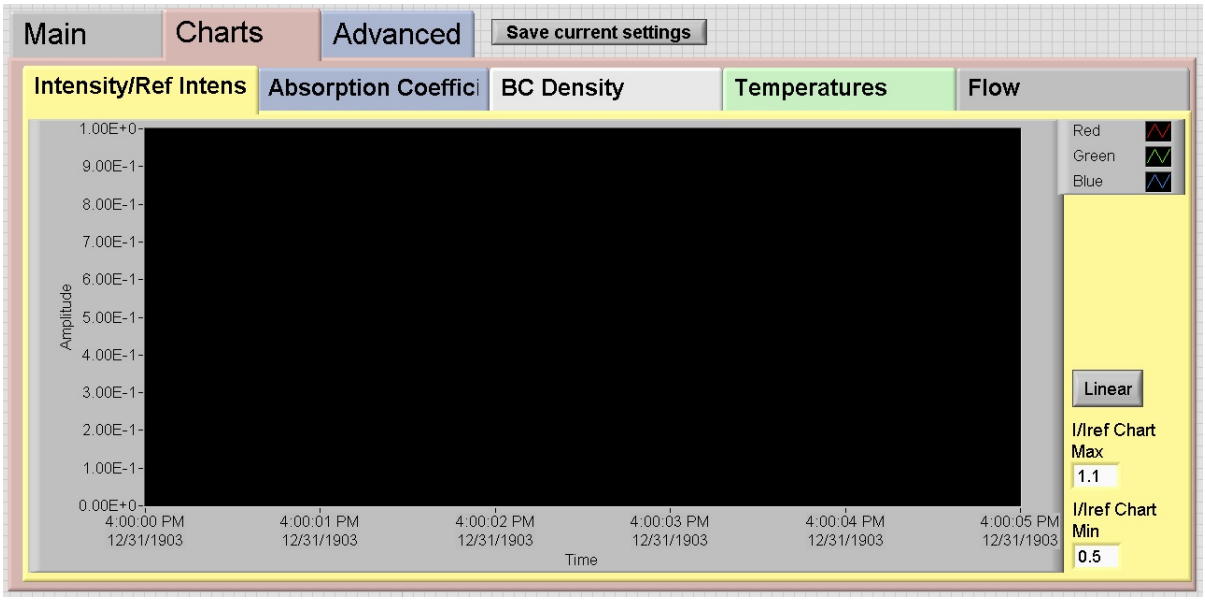

Figure 17: TAP GUI Charts Tab: Intensity/RefIntensity

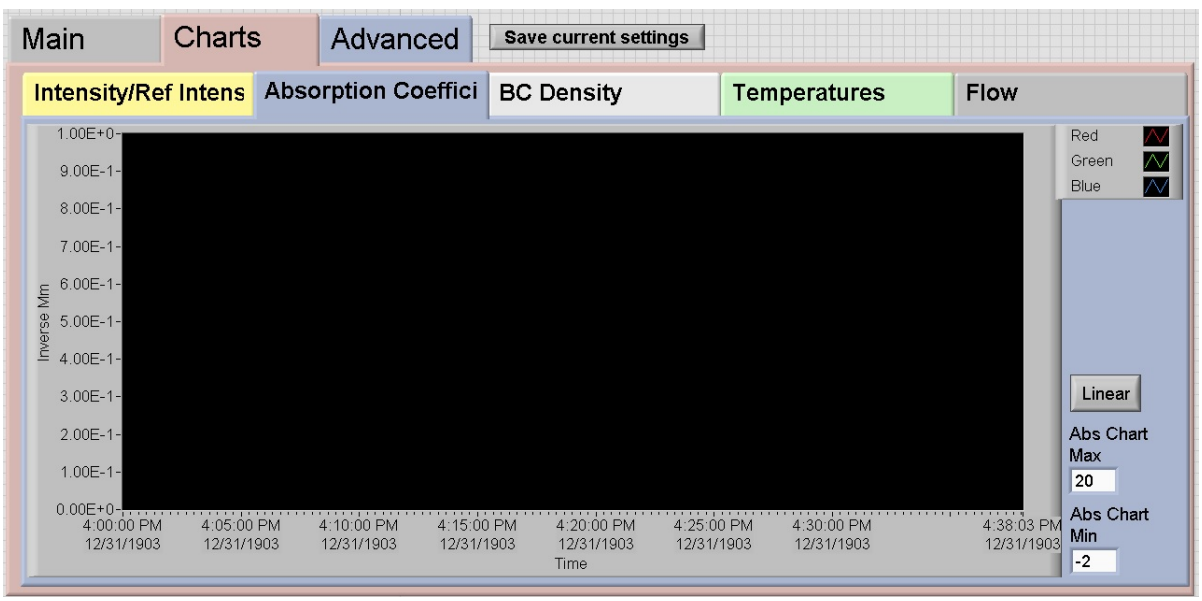

Figure 18: TAP GUI Charts Tab: Absorption Coefficients

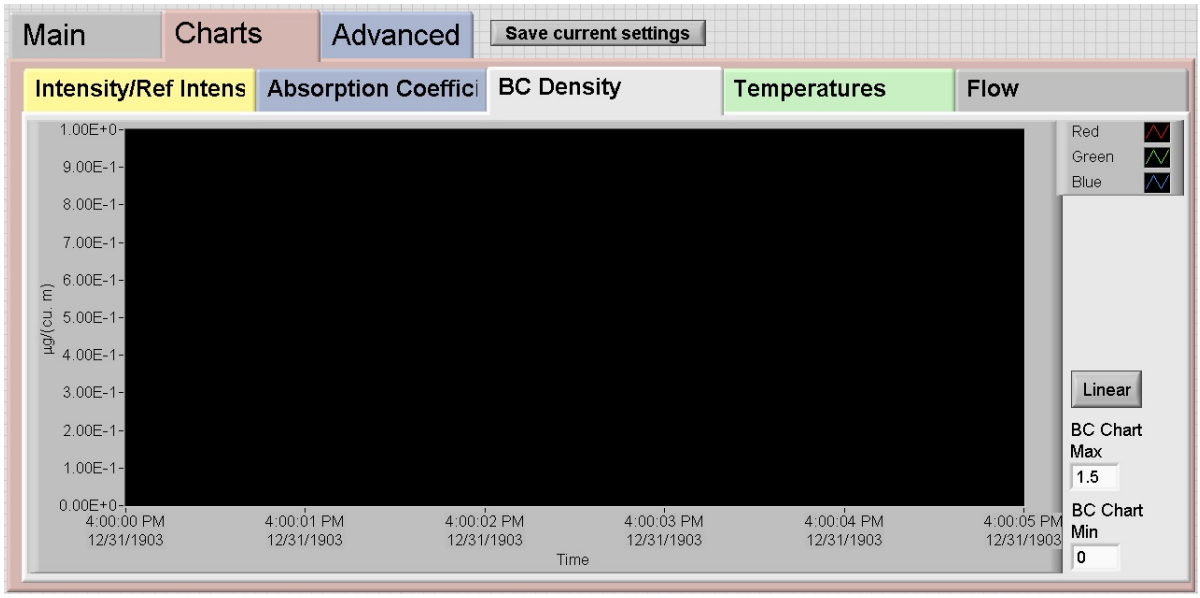

Figure 19: TAP GUI Charts Tab: Black Carbon Density

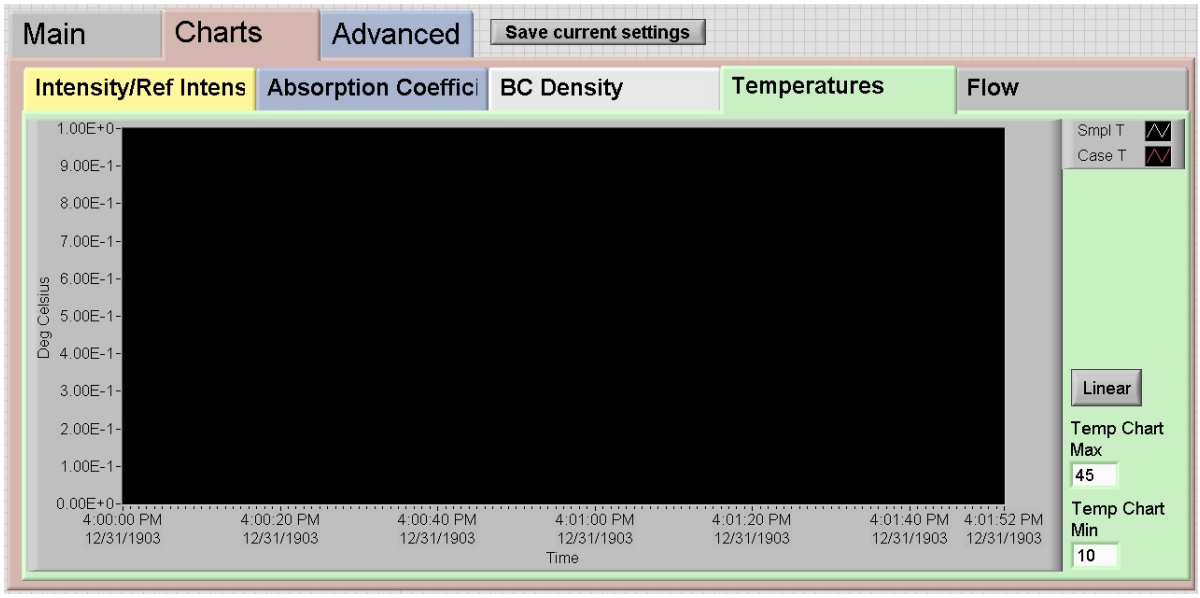

Figure 20: TAP GUI Charts Tab: Temperatures

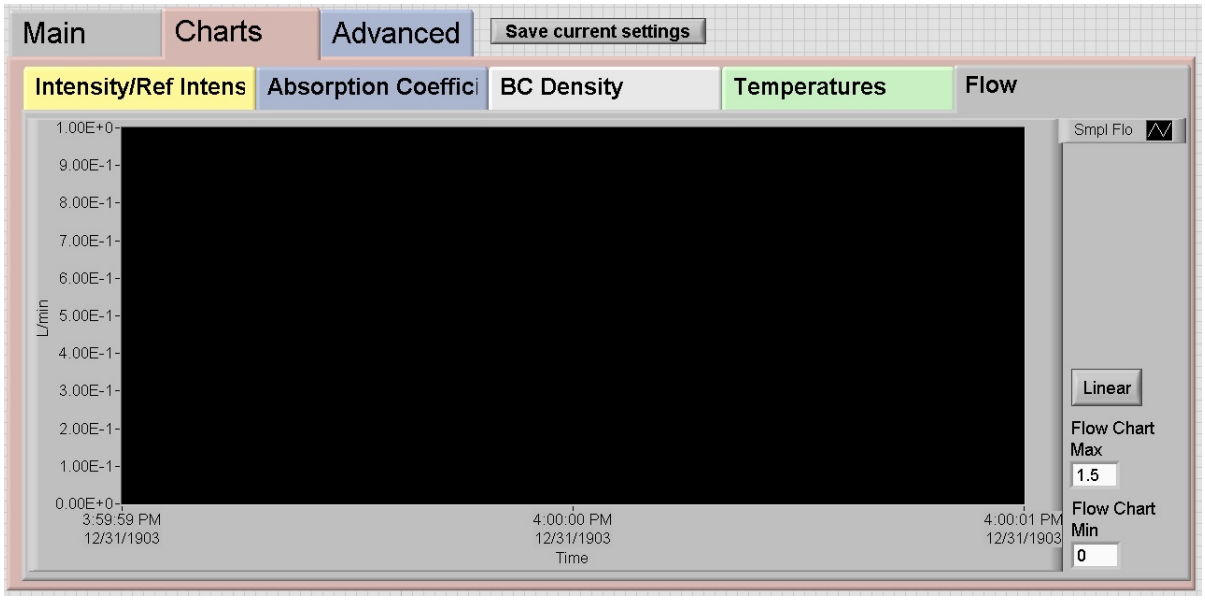

Figure 21: TAP GUI Charts Tab: Flow

All charts are accesible by clicking the corresponding tab. The x-axis is always time. The upper right corner of each subtab has a legend detailing the traces shown. All charts contain three controls:

Linear/Log	Changes the scaling of the y-axis.
Chart Max	Sets maximum y-value.
Chart Min	Sets minimum y-value.

5.3 Main Tab

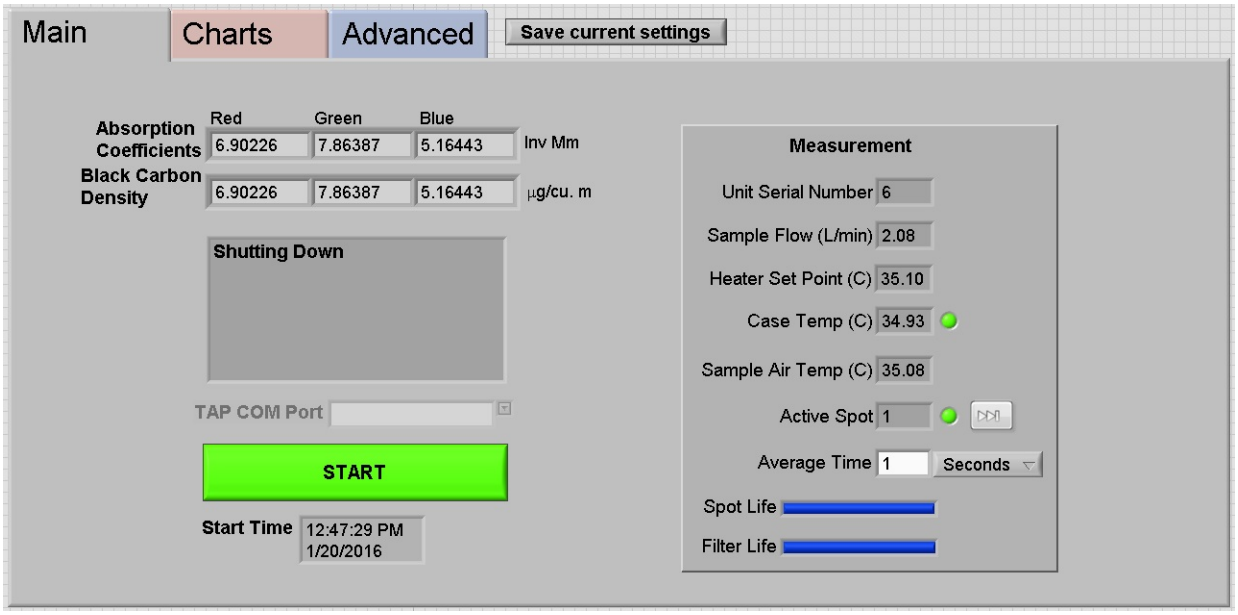

Figure 22: TAP GUI Main Tab

Absorption Coefficients	Displays calculated absorption coefficients in three wavelengths in inverse Mm.
Black Carbon Density	Displays absorption coefficients scaled by the Mass Extinction Efficiency from the Advanced tab. Has units of $\mu g/m^3$.
User Message Block	Gives the user updates about the current status of the TAP and GUI.
TAP COM Port	Select the COM port the TAP is connected to.
START/SHUTDOWN	Begins data collection/stops data collection when pressed.
Start Time	Displays the time that data taking begins.
Unit Serial Number	Displays serial number read in firmware.
Sample Flow	Displays current measurement of flow in L/min.
Heater Set Point	Displays current value from Advanced tab and firmware.
Case Temp	Displays current measurement of temperature of metal block under internal filter in C.
Sample Air Temp	Displays current measurement of air inlet temperature in C.
Active Spot	Displays current experimental spot drawing flow. Clicking the skip button will cause the unit to skip to the next spot immediately.
Average Time	The number of seconds to average the recorded light intensities. It is a running, boxcar average.
Spot Life	Displays the remaining life of the active spot.
Filter Life	Displays the remaining life of the current filter.

5.4 Output Data Format

The control software saves collected data in the "Data Directory" folder specified in the Advanced tab. A sample data set is included below. These .dat files contain both raw data directly from the instrument (in red below), as well as data with processing applied by the control software (see Theory of Operation). The file may be opened with any text editor.

5.4.1 Example File Header

Raw data at the end of the line has the Dark or Dark Ref value subtracted from it.
The absorption coefficient is calculated using the analysis in "Comment on 'Calibration and Intercomparison of Filter-Based Measurements of Visible Light Absorption by Aerosols'" by John A. Ogren 2010.
Sigma(abs)=f(Tr)*Sigma(0)-s*Sigma(scat): s = 0.02+/-0.02

Unit Serial Number: 22

Hardware Parameters:
Filter Material: Glass (Azumi M371)

Spot Area = 2.5281E-5 sq. m
Pall E70 correction from paper divided by 1.25 for rough equivalence.

Firmware Parameters:
firmware vers = 10.108
output interval = 1
stbl = 1.0
Tcase = 1.039004e-03, 2.376432e-04, 0.000000e+00, 1.616100e-07
Tair = 1.039004e-03, 2.376432e-04, 0.000000e+00, 1.616100e-07
Flow = -1.166108e-01, 4.338535e-02, 3.336363e-02, 3.287070e-02
pid = 250, 5, 1
lpf = 1, 0, 0, 0, 0

Software Parameters:
Software Version = 4.4.0
Port = COM4
White Filter Check Results[6] = 0.941648, 0.966884, 0.968108, 0.976536, 0.974668, 0.940121, 1.01651, 1.02871, 1.05487, 1.09712, 1.13925, 1.07085, 0.989169, 0.961492, 1.00110, 1.02287, 1.07244, 1.03554, 1.02547, 0.990426, 1.00892, 0.928665, 0.955096, 0.943986, 1.00000
LED Mode = 0
Red LEDs Percentage Power = 67, 70, 67, 68, 61, 70, 66, 68, 67, 70
Green LEDs Percentage Power = 100, 100, 100, 100, 100, 100, 100, 100, 100, 100
Blue LEDs Percentage Power = 89, 94, 89, 89, 83, 94, 86, 93, 89, 94
Software low pass filter is a 4 stage, single pole filter with effective first-order time constant of 2.6 seconds. Arguments are 2.17872e-1, 1.26719, -6.02159e-1, 1.27174e-1, -1.00721e-2.

5.4.2 Data Output

Date (yymmdd)	Time (24hr)	Active Spot	Ref Spot
150616	13:38:22	0	0
150616	13:39:08	1	1
150616	13:39:09	1	1

LPF	AvgTime	Red Abs Coef	Green Abs Coef	Blue Abs Coef
0	1	0	0	0
0	1	2.801488	1.749561	2.065082
1	60	1.413076	-0.706978	2.315388

Sample Flow (L/min)	Heater Set Point	Sample Air Temp (C)	Case Temp (C)
0	35.1	35.09	35.10
2.059	35.1	35.07	35.09
2.061	35.1	35.12	35.08

[6] White filter check values, I_{wf}, as described in Theory of Operation, are listed from left to right as follows: ch1_Red, ch1_Green, ch1_Blue, ... , ch8_Red, ch8_Green, ch8_Blue.

Red Ratio	Green Ratio	Blue Ratio	Dark
0.997581	0.997394	0.997485	-149.103897
0.943785	0.987831	0.982759	-147.742401
0.943781	0.987833	0.982752	-147.753006

Red	Green	Blue	Dark Ref
167783.0313	91418.8828	181310.578	2210413522
175655.8281	103790.117	191074.484	-138.529495
175645.9844	103784.82	191071.094	-138.667725

Red Ref	Green Ref	Blue Ref
167783	91418.88	181310.5781
186118.5	105068.7	194426.6406
186108.8	105063.1	194424.5

5.5 TAP.config File Settings

These settings are found in the TAP.config file in the C:TAP directory. They are the startup defaults for the GUI. If the file is missing or damaged a new, default file is generated. If this occurs, a white filter check needs to be run.

File Paths	Value
Data File Path	The full path to the directory where data (and raw data, if Raw Data Dump = TRUE) is to be saved, e.g. "/C/TAP/DATA".

Communication	Value
COM Port	The serial port address, e.g. "COM3".

Data Settings	Values
Average Time	Number of second to collect data to calculate the mean of the absorption coefficient.
Average Time Unit	1, 60, or 3600 for seconds, minutes, or hours respectively as the time unit for Average Time.
File Size	Approximate number of measurements for 1 data file to hold before a new one is created.
Start Spot	The experimental spot that the program will begin on. Normally 1.
End Spot	The experimental spot that the program will end on. Normally 8.
Red Spot Switching Threshold	Threshold for spot change. Either settable as 0.5 or 0.7 transmission. This is recorded here as 5 or 7.
Green Spot Switching Threshold	Threshold for spot change. Either settable as 0.5 or 0.7 transmission. This is recorded here as 5 or 7.
Blue Spot Switching Threshold	Threshold for spot change. Either settable as 0.5 or 0.7 transmission. This is recorded here as 5 or 7.
Cal Temp	Temperature in Kelvin that the unit was calibrated at. Used for flow correction.

Ref Rel St Dev	The standard deviation must be below this value for a spot's data to be considered stable and begin recording data at that spot after each spot change.
Max Counter	Maximum number of times to retry Ref Rel St Dev criteria.
Last White Filter	The results of the last white filter check - 1 separated by <tab>, described in Theory of Operation as I_{wf}. White filter values are listed from left to right as follows: ch1_Red, ch1_Green, ch1_Blue, ... , ch8_Red, ch8_Green, ch8_Blue.
Pressure	Current pressure in Pascals.
Cal Pressure	Pressure in Pascals that the unit was calibrated at. Used for flow correction.
Mass Extinction Efficiency	The factors to convert absorption coefficients to $\mu g/m^3$ of black carbon for each color, e.g. "7 <tab> 8 <tab> 9".
Filter Material	Selects the fiber filter type, spot size, and correction to use.
Raw Data Dump	If FALSE, does nothing. If TRUE creates a RAW_TAP_SN#_date_time.dat file with the raw output from the TAP.
Spot Change Timer?	If FALSE, the program will remain on a given spot until a color's switching threshold is reached. If TRUE, the program will remain on a given spot until Spot Change Time (s) is reached or the threshold is reached, whichever comes first.
Spot Change Time (s)	Amount of time in seconds to remain on each experimental spot.
Heater Set Point	The set point for the internal heater. Cannot be set above 50C.
Stop before White Filter?	If FALSE, the program will skip the initial dialog box asking if the filter is new and immediately begin taking data. If TRUE, the program puts up a dialog box asking the user if the filter is new. If the user responds yes, then a white filter check will begin.
Stop after White Filter?	If FALSE, the program will immediately begin taking data after the white filter check is complete with the filter installed on the inlet. If TRUE, the program puts up a dialog box telling the user to remove the filter and then hit okay before normal data operation starts.

Auto Start	If FALSE, allows user to check communication and start settings on the Advanced tab before beginning a run when the user pushes start of the Main tab. If TRUE, immediately starts run.
Low Pass Filter	If FALSE, software low pass filter is off. If TRUE, software low pass filter is on. Software low pass filter is a 4 stage, single pole filter with effective first-order time constant of 2.6 seconds. Arguments are 2.17872e-1, 1.26719, -6.02159e-1, 1.27174e-1, -1.00721e-2.

Display Settings	**Values**
I/Iref Log	Startup value. If FALSE, scale is linear. If TRUE, scale is logarithmic.
I/Iref Min	Startup minimum value.
I/Iref Max	Startup maximum value.
Flow Log	Startup value. If FALSE, scale is linear. If TRUE, scale is logarithmic.
Flow Min	Startup minimum value.
Flow Max	Startup maximum value.
Abs Log	Startup value. If FALSE, scale is linear. If TRUE, scale is logarithmic.
Abs Min	Startup minimum value.
Abs Max	Startup maximum value.
Temp Log	Startup value. If FALSE, scale is linear. If TRUE, scale is logarithmic.
Temp Min	Startup minimum value.
Temp Max	Startup maximum value.
BC Log	Startup value. If FALSE, scale is linear. If TRUE, scale is logarithmic.
BC Min	Startup minimum value.
BC Max	Startup maximum value.

6 TAP Specifications

Category	**Value**
Centroid wavelengths and (FWHM), nm	640 (25); 520 (35); 465 (22) or 365 (15)
Filter Media	Glass fiber, 47 mm diameter
Volumetric flow rate	2 LPM
Vacuum requirement	9 inHg
Noise (σ of 60-sec averages on filtered air), Mm	~0.2, RGB ~0.5, UV
Number of Sample Spots	8
Number of Reference Spots	2
Dimensions (L $\times$ W $\times$ H)	160mm $\times$ 110mm $\times$ 115mm (6.25in $\times$ 4.25in $\times$ 4.5in)
Weight	1.6 kg (3.5 lbs)
Power Consumption	70 W @ 90-264 VAC, using supplied adapter 3.0 A @ 24 VDC
Power Adapter Dimensions (L $\times$ W $\times$ H)	132mm $\times$ 58mm $\times$ 30.5mm (5.2 in $\times$ 2.3 in $\times$ 1.2 in)
Mounting	4 removable rubber feet in rectangular pattern, 85.73mm $\times$ 111.13mm (3.375 in $\times$ 4.375)
Serial communications	RS232, 57600 baud, no parity, 8 data bits, 1 stop bit.

7 RS-232 Commands

RS-232 communications may be used to control the unit directly, bypassing the Brechtel control software. Brechtel does not recommend using direct RS-232 control for collection of raw, unprocessed instrument data, as these values are included in the Brechtel TAP control software data records (See Output Data Format in Section 4).

The TAP serial communications have been specially-formatted to maintain compatibility with legacy software. The port should be configured to 57600 baud transmission with 8 data bits, no parity bits, and 1 stop bit. When initially powered on, the TAP idles, leaving all valves closed (and thus preventing flow through the instrument). It will, however, immediately begin broadcasting its state over the serial connection (See State Transmission Record Format below).

The instrument stores total accumulated spot airflow in non-volatile memory, so if power to the instrument is interrupted during manual operation, measurements can be resumed by simply enabling flow through the desired spot. However, Brechtel recommends always starting a new spot after loss of instrument power. Both the total spot airflow and intensity measurements are reset during manual operation filter changes.

Commands are issued over-the-wire by transmitting the command as ASCII text, followed by a carriage return and line feed. In most serial communications software, this can be accomplished by simply typing the command and pressing the <Enter> key.

7.1 Universal Commands

At any time, the following four commands are available.

main Returns to the main menu

? Queries the current menu

hide Disables unpolled data transmission

show Enables unpolled data transmission

7.2 Main Menu Commands

This is the default state upon power up.

cfg Requests the configuration menu

cal Requests the calibration menu

stop Stops current filter, beginning a filter change.

go Starts new filter, completing a filter change. When preceded by the stop command, increments <Filter ID>.

spot Requests active spot.

spot=0 Stop sampling and flow.

spot=n Switches <Active spot> to n and begins sampling. spot=+ Switches <Active spot> to next spot and begins sampling.

Warning: main, cfg, and cal commands may pause unpolled data reports for approximately 15 seconds.

7.3 Configuration Menu Commands

sn Requests the serial number.

fw Requests the firmware version.

rst Performs a full software reset, clearing all stored information and calibration. Not recommended by Brechtel.

oint Requests output interval in seconds

oint=s Sets output interval to s seconds

lpf Shows digital filter settings.

lpf=args Sets digital filter settings. Default filter is a 4-stage single-pole low-pass filter, with effective first-order time constant of 2.6 seconds. args should be formatted as B0,B1,B2 ,B3,B4 with default lpf=2.17872e-1, 1.26719, -6.02159e-1, 1.27174e-1, -1.00721e-2. When off, lpf =1,0,0,0,0. If using GUI, will be turned off.

hsp Requests case heater setpoint in degrees C

hsp=T Sets the case heater setpoint to t degrees C. Temperature should be formatted as ##.#

stbl Requests the case temperature window for stable operation. Exceeding this window will raise a status flag.

stbl=t Sets the case temperature window. The temperature window will be defined by T +/- t. Format as ##.#

7.4 Calibration Menu Commands

Tc Requests the case temperature calibration.

Tc=args Sets the case temperature calibration. args corresponds to a third degree polynomial, with constant first, and should be formatted as c0,c1,c2,c3. Default setting is Tc=1.039004e-3, 2.376432e-4, 0, 1.6161e-7.

Ta Requests the inlet flow temperature calibration.

Ta=args Sets the case temperature calibration. args corresponds to a third degree polynomial, with constant first, and should be formatted as d0,d1,d2,d3. Default setting is Ta=1.039004e-3, 2.376432e-4, 0, 1.6161e-7.

flow Requests the flow calibration.

flow=args Sets the flow calibration. args corresponds to a third degree polynomial, with constant first, and should be formatted as f0,f1,f2,f3. Internally clips to 0.0 SLPM min, 3.0 SLPM max. Default values are -8.03700e-01,1.20400e+00,-4.99400e-01,9.74000e-02

pid Requests the instrument PID gain settings.

pid=args Sets the PID gain settings. Format args as p,i,d led Requests the LED mode and intensity settings. led=args Sets the LED mode and intensity settings. Format args as m,r,g,b with defaults 1,100,100,100.

7.5 Changing a filter command sequence

1. hide
2. spot=0
3. stop
4. Physically change the filter (See Installing a Filter in Section 3)
5. go
6. spot=1
7. show

8 Instrument Record Format

8.1 Instrument Record Fields

Instrument state, including data and status, is transmitted in 458-byte records of comma-separated ASCII text. Records are terminated by an additional carriage return and line feed. There are 49 fields in total:

1. <Record type>
2. <Status flags>
3. <Elapsed time>
4. <Filter ID>
5. <Active spot>
6. <Flow rate>
7. *<Sample volume for active spot>*
8. *<Case temperature>*
9. *<Sample air temperature>*
10. - 49. *<Channel component intensities>*

An example record, for reference, with line feeds added for readability:
03, 0002, 00003ef7, 0018, 01, 1.996, *0.00142*, *37.00*, *34.22*, *c343ef6c, 48b09b55, 4834423c, 486dc150, c3423a45, 48758f3c, 48011951, 4827deac, c2bd6321, 487189bf, 47fc6640, 48213bd4, c2ab3f0d, 48756a90, 480020b0, 48250060, c2c627a3, 486fdf58, 480007a6, 4828f8c7, c2f23422, 48702856, 47f488a6, 481fa9d0, c38221db, 4883722d, 480480a7, 4830920e, c3893305, 4881ff54, 47ff16d0, 48289c3b, c3301adc, 48880fb4, 4806eb88, 4833d955, c358a903, 48a4f341, 48246cf4, 4857f0f1*

Record type	Currently recorded as 03. Has no effect on instrument operation.
Status flags	TAP status is recorded as a packed 4-digit hex integer. Note that bits are additive: for example, a value of 0x0300 would indicate that both a temperature error (0x0200) and a lamp/filter error (0x0100) were detected. Enumerated in table 2.
Elapsed time	Elapsed time is recorded in seconds since instrument power-up. It is formatted as an 8-digit hex integer and unused by the Brechtel TAP control software. For example: 0x00003ef7 = 16119 seconds.
Filter ID	The filter ID increments on every stop+go command sequence and can only be reset with an rst command (see Configuration Menu below). It is stored in non-volatile memory, formatted as a 4-digit hex integer, and unused by the Brechtel TAP control software. For example: 0x0018 = 24
Active spot	The active spot field indicates which sample channel is currently active. It is formatted as a 2-digit decimal integer. An active spot of 00 indicates that no spot is active. Example: 01 = Sample channel 1
Flow rate	Flow rate is given in SLPM. It is formatted as a 4-digit fixed-point decimal. For example: 1.996 = 1.996 SLPM.
Sample volume for active spot	This field describes the total aggregate flow through the sample channel for this filter. It is formatted as a 6-digit fixed-point decimal with units of cubic meter. For example: 0.00142 = 0.00142 m^3
Case temperature	This field indicates the temperature of the instrument body, given in degrees Celsius. It is formatted as a 4-digit fixed-point decimal. For example: 35.00 = 35.00 ÂºC
Sample air temperature	This field indicates the temperature of the sample inlet airflow, given in degrees Celsius. It is formatted as a 4-digit fixed-point decimal. For example: 34.22 = 34.22 ÂºC
Channel component intensities	Readings are given as tuples of (dark, red, green, blue) component intensities for each channel. These are then concatenated into a single list: <CH0 DARK>, <CH0 RED>, <CH0 GRN>, <CH0 BLU>, <CH1 DARK>, <CH1 RED>, <CH1 GRN>, <CH1 BLU>, <CH2 DARK>, <CH2 RED>, <CH2 GRN>, <CH2 BLU>... Channel 0 is used as reference for sample <Active spot> = [2, 4, 6, 8]. Channel 9 is used as reference for sample <Active spot> = [1, 3, 5, 7]. Please see Channel Component Conversion for conversion details.

8.2 Flag Bit Description

0x0400 (0000 0100 0000 0000)	Case temperature unstable (above or below case temperature window)
0x0200 (0000 0010 0000 0000)	Temperature error
0x0100 (0000 0001 0000 0000)	Lamp or filter error
0x0002 (0000 0100 0000 0010)	Flow error
0x0001 (0000 0000 0000 0001)	Filter changing

Table 2: TAP Status Flags

8.3 Channel Component Conversion

Individual intensities are represented using a multi-step conversion:

1. The IEEE754 single precision (32-bit) floating point intensity reading from the detector is converted to raw bits.
2. These bits are reinterpreted as a 32-bit decimal integer.
3. That integer is converted to hexadecimal base.
4. The hexadecimal integer is added to the record (like the rest of the record, it is encoded as an ASCII string on the wire).

For example, reversing this process using a value from the example record above yields:

1. $0xc343ef6c = (3276009324)_{10}$
2. $(3276009324)_{10} = (11000011010000111110111101101100)_2$
3. $(11000011010000111110111101101100)_2 = -1.9593524e2$

9 USB Connection for Optional BMI Tablet

9.1 Lenovo/Dell Tablets

When purchased with the optional BMI tablet, the instrument will be shipped with a Plus Port, a tablet power supply, and a serial/USB converter.

The Plus Port allows the tablet to charge (in USB slave mode) while simultaneously reading data from the serial/USB converter (in USB host mode). To operate the instrument with the BMI-supplied tablet, connect the tablet power supply to the Plus Port, the serial converter to the Plus Port, and the Plus Port to the tablet (see figure 23).

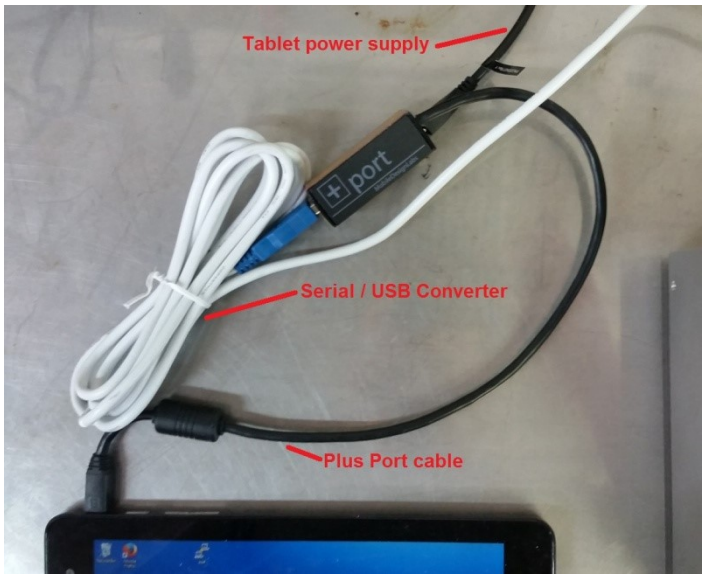

Figure 23: BMI Tablet/Plus Port Connection

9.2 Toshiba Tablets

When purchased with the optional BMI tablet, the instrument will be shipped with a color-coded Y-USB cable, a gender changer, a tablet power supply, and a serial/USB converter.

The Y-USB cable allows the tablet to run off AC power (keeping the battery at its current charge) while simultaneously reading data from the serial/USB converter (in USB host mode). To operate the instrument with the BMI-supplied tablet, connect the tablet power supply to the red end of the Y-USB cable, the micro USB end of the Y-USB cable to the tablet, and the final end of the Y-USB cable to the gender changer and then the serial converter.

9.3 Laptop

When purchased with the optional BMI laptop, the instrument will be shipped with a laptop power supply and a serial/USB converter. To operate the instrument with the laptop, connect the power supply and the serial/USB converter to the laptop. Use a USB port on

the laptop to connect the converter. Determine the correct COM port number assigned by the computer to the converter. Connect the serial port end (DB9) of the converter to the rear panel of the TAP. In the TAP Reader software, enter the correct COM port under the Advanced tab.

10 Contact Us

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