**Kunak**

# Test of the Air Pro

# for use as an Indicative Monitor for $PM_{10}$ and $PM_{2.5}$

June 2023

*Move Forward with Confidence*

BUREAU VERITAS

This page is left blank intentionally

# DOCUMENT CONTROL SHEET

| Issue/Revision | Draft for Comment | Final |
|---|---|---|
| Date | 09 March 2023 | 27 June 2023 |
| Submitted to | Kunak | Kunak |
| Prepared by | Jichu Cai | Jichu Cai |
| Signature |  |  |
| Approved by | Dr David Harrison | Dr David Harrison |
| Signature |  |  |
| Project number | AIR17810339 | AIR17810339 |

Disclaimer

This Report was completed by Bureau Veritas on the basis of a defined programme of work and terms and conditions agreed with the Client. Bureau Veritas' confirms that in preparing this Report it has exercised all reasonable skill and care taking into account the project objectives, the agreed scope of works, prevailing site conditions and the degree of manpower and resources allocated to the project.

Bureau Veritas accepts no responsibility to any parties whatsoever, following the issue of the Report, for any matters arising outside the agreed scope of the works.

This Report is issued in confidence to the Client and Bureau Veritas has no responsibility to any third parties to whom this Report may be circulated, in part or in full, and any such parties rely on the contents of the report solely at their own risk.

Unless specifically assigned or transferred within the terms of the agreement, the consultant asserts and retains all Copyright, and other Intellectual Property Rights, in and over the Report and its contents.

Any questions or matters arising from this Report should be addressed in the first instance to the Project Manager.

Bureau Veritas UK Limited
5th Floor, 66 Prescott Street
London
E1 8HG

Central: +44 (0) 845 6000 1828
Registered in England 1758622
www.bureauveritas.co.uk

Registered Office
Suite 206, Fort Dunlop
Fort Parkway
Birmingham
B24 9FD

# Table of Contents



# List of Figures



# List of Tables

# EXECUTIVE SUMMARY

Two Kunak Air Pro instruments were operated alongside a Palas Fidas 200, both of which monitor both $PM_{10}$ and $PM_{2.5}$. A comparison was made in line with the Performance Standards for Indicative Ambient Particulate Monitors, Version 4, dated August 2017[1]. In accordance with the criteria described therein, a summary of the performance of the instrument is given in the overleaf Table and summarised below.

The Air Pro passes all of the criteria set out in the Performance standard for indicative instruments for collecting $PM_{10}$ and $PM_{2.5}$ data. Kunak have made the decision to automatically slope correct $PM_{10}$ data by dividing 0.596 and slope correct $PM_{2.5}$ data by dividing by 0.667. Therefore users should not make these additional corrections.

In order to be used for indicative purposes the Air Pro must be set up in the same configuration as which it was tested, namely the following must be installed:

- Sensor Type and Firmware Version: Alphasense OPC-N3 Firmware Version 1.17a.B. Modifications to the sensor firmware version would require verification by the certification committee. Modifications to the sensor itself may require repeating the field test or comparing systems operating different versions of the sensor to show that there are no differences to the measurements.

- Algorithm Version: KAIR_OPCN3_31. Modifications to the algorithm will need approval by the certification committee and if modifications are made to the PM mass calculation then this would potentially require the field test to be repeated.

**Certification Range:**

| | |
|---|---|
| **$PM_{10}$** | To be decided by the certification committee |
| **$PM_{2.5}$** | To be decided by the certification committee |

[1] Performance Standards for Indicative Ambient Particulate Monitors, Version 4, Environment Agency, August 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/642895/LIT_7070.pdf

| **Test** | **Results** | **MCERTS Specification** |
|---|---|---|
| Constancy of the sample volumetric flow | Prior permission was sought and received not to perform this test as the instrument utilises a fan not a pump. | Sample volumetric flow averaged over the sampling time to remain constant within ± 3% of the rated value. All instantaneous values to remain within ± 5% of the rated value. |
| Tightness of the sampling system | 1.44% | Leakage not to exceed 2% of sampled volume. |
| Maintenance interval | The manufacturer recommends that users clean the PM inlet if it becomes dirty. It is further recommended to change the PM sensor after 2 years operation. | Greater than or equal to two weeks. |

| **Performance characteristics when monitoring $PM_{10}$** | | |
|---|---|---|
| **Test** | **Results** | **MCERTS Specification** |
| Intra-instrument uncertainty for the reference method | Only one Palas Fidas 200 was used during the testing of the Air Pro.<br>0.33 µg $m^{-3}$ was calculated during operation of two Palas Fidas 200s at a similar site during 2014. | ≤ 2.5 µg $m^{-3}$. If only a single reference method instrument is available, then values from previous tests performed by the same laboratory/network using identical pattern of samplers can be used. If those are not available a default value of 0.67 µg $m^{-3}$ can be assumed. |
| Intra-instrument uncertainty for the candidate method | 1.74 µg $m^{-3}$<br>(All data, n=306)<br>1.74 µg $m^{-3}$<br>(<30 µg $m^{-3}$, n=302)<br>2.47 µg $m^{-3}$<br>(≥30 µg $m^{-3}$, n=4) | ≤5 µg $m^{-3}$ for all data as well as for the subsets: less than and greater than or equal to 30 µg $m^{-3}$ for $PM_{10}$. The “greater than” data subset shall contain at least 8 data pairs. If 80 data pairs are produced still without generating the required 8 data pairs in the “greater than” subset then this is considered sufficient and the testing may be terminated. |
| Highest resulting uncertainty estimate comparison against data quality objective (measurement uncertainty) | All Data:<br>$W_{CM}$ = 81.1%<br>(n = 306. 7of 313 points were excluded due to low data capture.)<br>All Data after slope correction by dividing by 0.596:<br>$W_{CM}$ = 12.2%<br>(n = 306)<br>$PM_{2.5}$ ≥18 µg $m^{-3}$ after slope correction by dividing by 0.596:<br>$W_{CM}$ = 46.6%<br>(n = 4) | $W_{CM}$ ≤ 50%. The resultant expanded uncertainty is assessed for the full dataset, and the dataset split to be greater than 30 µg $m^{-3}$. |

| **Performance characteristics when monitoring $PM_{2.5}$** | | |
|---|---|---|
| **Test** | **Results** | **MCERTS Specification** |
| Intra-instrument uncertainty for the reference or equivalent method | Only one Palas Fidas 200 was used during the testing of the DM30 Dustsens.<br>0.25 µg $m^{-3}$ was calculated during operation of two Palas Fidas 200s at a similar site during 2014. | ≤ 2.5 µg $m^{-3}$. If only a single reference method instrument is available, then values from previous tests performed by the same laboratory/network using identical pattern of samplers can be used. If those are not available a default value of 0.67 µg $m^{-3}$ can be assumed. |
| Intra-instrument uncertainty for the candidate method | 0.81 µg $m^{-3}$<br>(All data, n=306)<br>0.75 µg $m^{-3}$<br>(<18 µg $m^{-3}$, n=292)<br>0.64 µg $m^{-3}$<br>(≥18 µg $m^{-3}$, n=14) | ≤5 µg $m^{-3}$ for all data as well as for the subset: less than and greater than or equal to 18 µg $m^{-3}$ for $PM_{2.5}$. The “greater than” data subset shall contain at least 8 data pairs. If 80 data pairs are produced still without generating the required 8 data pairs in the “greater than” subset then this is considered sufficient and the testing may be terminated. |
| Highest resulting uncertainty estimate comparison against data quality objective (measurement uncertainty). | All Data:<br>$W_{CM}$ = 67.0%<br>(n = 306)<br>All Data after slope correction by dividing by 0.667:<br>$W_{CM}$ = 10.6%<br>(n = 306)<br>$PM_{2.5}$ ≥18 µg $m^{-3}$ after slope correction by dividing by 0.667:<br>$W_{CM}$ = 40.9%<br>(n = 14) | $W_{CM}$ ≤ 50%. The resultant expanded uncertainty is assessed for the full dataset, and the dataset split to be greater than 18 µg $m^{-3}$. |

# 1. Legislative Background

The European Commission (EC) Directive 2008/50/EC[2] was accepted into UK law in June 2010. Member States of the European Union (EU) are required to measure the mass of particulate matter (PM) below 10 microns diameter ($PM_{10}$) and below 2.5 microns diameter ($PM_{2.5}$). Concentrations are reported as 24-hour averages, and for $PM_{10}$ it is a requirement that there are fewer than 35 exceedences of 50 µg $m^{-3}$ per year, and that the annual average is below 40 µg $m^{-3}$. For $PM_{2.5}$ there is no daily limit, though there is an annual average target of 20 µg $m^{-3}$. The European reference methods for quantifying $PM_{10}$ and $PM_{2.5}$ are set out in the standard EN12341[3]. The reference instruments sample one filter every 24 hours (as per the reporting requirements), and there is a potential delay of several weeks before the filters are weighed, and the concentrations calculated.

While there is no legal mandate, there is often a need to have real-time data at a frequency of at least hourly. In light of this, the EC allows Member States to use instruments that can be proven equivalent to the European Reference Methods[4]. Many instruments are available that use a variety of methods to quantify PM. Candidate instruments are tested in duplicate against the reference methods for a minimum of 40 days at each of a minimum of four tests that cover a range of test locations and seasons. A mathematical analysis is undertaken to show that the slope and intercept are not significantly different from 1 and 0 respectively, and that the expanded uncertainty at the limit value is less than 25%. It is possible for a slope and/or intercept correction factor to be introduced; however, it is a requirement that the same correction factors are used for all the datasets.

Within the United Kingdom (UK), the Environment Agency (in collaboration with CSA) runs a Monitoring Certification Scheme (MCERTS) for Continuous Ambient Mass Monitoring Systems (CAMS) and this has been used successfully for several years to certify instruments that are proven equivalent to the European Reference methods[5]. Such certified instruments tend to be relatively large and expensive and often require air-conditioned enclosures in which to operate effectively.

Within the UK, there is often a requirement to monitor PM using cost-effective weatherproof methods that provide real-time data at a high frequency of 15 minutes or lower. Such equipment needs to be able to accurately identify that there has been a significant spike in PM concentrations, but it is not necessarily a requirement to accurately know the magnitude of this spike. As such, these instruments could be described as giving an “indication” of PM, but are not intended to be equivalent to the European Reference Methods, and therefore are not suitable for compliance reporting. Typically, “indicative” methods can be used as a first approximation to compliance and then followed with more accurate methods that conform to the European reference methods for compliance measurement purposes. Indicative instruments are most commonly situated at industrial processes that are regulated by the EA or Local Authorities (LAs).

The EA have developed a certification scheme for indicative instruments[1]. As with the equivalent tests, candidate instruments are tested in duplicate against the reference or equivalent method for a minimum of 40 days; however, it is just a requirement that there is a single test rather than at least four. Further, the mathematical analysis requires that the expanded uncertainty at the limit value is less than 50%, rather than 25% as is required for equivalent instruments.

---

[2] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe

[3] Standard EN12341:2014 Ambient air - Standard gravimetric measurement method for the determination of the $PM_{10}$ or $PM_{2,5}$ mass concentration of suspended particulate matter

[4] European Standard EN16450:2017 Ambient air - Automated measuring systems for the measurement of the concentration of particulate matter ($PM_{10}$; $PM_{2,5}$)

[5] https://www.csagroup.org/en-gb/services/mcerts/mcerts-product-certification/mcerts-certified-products/mcertscertified-productscontinuous-ambient-air-monitoring-system-mcerts-for-uk-particulate-matter/

# 2. Methodology

From the 1st April 2022 to 7th February 2023, two candidate Air Pro were collocated with a Palas Fidas 200. The Palas Fidas has previously been shown to be equivalent to the European reference Method. The location of the tests was in Manchester University Fallowfield. The primary reasons for choosing this location were that:

- Manchester University undertook the monitoring as an independent organisation;
- the zero leak tests were supervised by the National Physical Laboratory (NPL) which has ISO17025 accreditation for these tasks.

The serial numbers for the two Air Pro monitors tested were 0321180036 and 0321180037.

The Sensor Type and Firmware Version: Alphasense OPC-N3 Firmware Version 1.17a.B.

The algorithm version was KAIR_OPCN3_30.

The instruments produced 5 minute average concentrations, and these were averaged to 24 hour averages. The 24 hour average was only valid when there was at least 75% data capture for that day.

The Air Pro systems performed very well throughout the tests. Of the 313 days' of data, 16 had data deleted, and of these, 1 had more than 25% of the data deleted and as such the 24 hour average was considered invalid. Only around 0.3% of 5 minute data points were deleted for both Air Pro instruments. The performance standard states "Data may be removed from the data set when there are sound technical reasons for doing so. This data ratification process applies in particular to spikes that can be considered unrealistic for a particular data set. The data ratification process cannot deplete the data set below the data capture level of 90%.". It is believed that the use of the algorithm is within these criteria.

The following Sections discuss the results in the order that they are discussed in the performance standard.

# 3. Certification Range

The instrument is designed to operate over a measurement range of 0 µg $m^{-3}$ to 10,000 µg $m^{-3}$.

As with all certification projects, it is not always possible to achieve these high concentrations over the course of the test. The highest concentrations observed during the test were:

- Maximum Hourly $PM_{10}$ 41µg $m^{-3}$;
- Maximum Hourly $PM_{2.5}$ 38 µg $m^{-3}$;
- Maximum 24-Hour $PM_{10}$ 22 µg $m^{-3}$;
- Maximum 24-Hour $PM_{2.5}$ 22 µg $m^{-3}$.

The decision as to the appropriate certification range is left to the Certification Committee.

# 4. Constancy of Sample Volumetric Flow

Prior permission was sought and received not to perform this test as the instrument utilises a fan not a pump.

# 5. Tightness of the Sampling System

The performance standard states that “the tightness of the sampling system shall not exceed 2% of sampled volume”.

Leak tests were performed by placing a HEPA filter on the inlet to the instruments on 7th February 2023. Each instrument was tested consecutively and hence observed different ambient concentrations throughout the test. For 0321400108, $PM_{10}$ and $PM_{2.5}$ were 13.54 µg $m^{-3}$ and 9.93 µg $m^{-3}$ before the HEPA test and $PM_{10}$ and $PM_{2.5}$ were 0.15 µg $m^{-3}$ and 0.14 µg $m^{-3}$ whilst the HEPA filters was on, which corresponds to a leak rate of 1.44% and 1.07% respectively. For 0321400109, $PM_{10}$ and $PM_{2.5}$ were 13.41 µg $m^{-3}$ and 10.17 µg $m^{-3}$ before the HEPA test and both were 0.03 µg $m^{-3}$ whilst the HEPA filters was on, which corresponds to a leak rate of 0.33% and 0.25% respectively. All of these are below the required 2%, but the highest of these (1.44%) shall go on the certificate.

# 6. Intra Instrument Uncertainty of the Reference or Equivalent Method

Whilst only a single Palas Fidas 200 was operated during the testing of the Air Pro, two identical instruments were operated in parallel between 27th February and 2nd June 2014 at a similar site. Calculations of the intra instrument uncertainty were undertaken using the methodology described in Technical Specification 16450[4].

For $PM_{10}$, the 24 hour intra instrument uncertainty was shown to be 0.33 µg $m^{-3}$ and it is this value that is used in the calculation of the $PM_{10}$ expanded uncertainty of the Air Pro. As such, the instrument meets the intra instrument uncertainty for the reference or equivalent method specification for $PM_{10}$.

For $PM_{2.5}$, the 24 hour intra instrument uncertainty was shown to be 0.25 µg $m^{-3}$ and it is this value that is used in the calculation of the $PM_{2.5}$ expanded uncertainty of the Air Pro. As such, the instrument meets the intra instrument uncertainty for the reference or equivalent method specification for $PM_{2.5}$.

# 7. Intra Instrument Uncertainty of the Candidate Method

The performance standard states that the "Intra instrument uncertainty for the candidate method should be ≤5 µg $m^{-3}$ for all data as well as for the subsets: less than and greater than or equal to 30 µg $m^{-3}$ for $PM_{10}$ and 18 µg $m^{-3}$ for $PM_{2.5}$. Each "greater than" data subset shall contain at least 8 data pairs. If 80 data pairs are produced still without generating the required 8 data pairs in the "greater than" subset then this is considered sufficient and the testing may be terminated".

Calculations of the intra instrument uncertainty were undertaken using the methodology described in EN16450[4], and the results are shown for $PM_{10}$ in Table 7.1. Calculations were performed on the 24-hour average data (after slope correction as explained in the following Section). For all three categories, the intra instrument uncertainty ($u_{bs}$) was lower than the required 5 µg $m^{-3}$, and as such, the instrument meets the intra instrument uncertainty for the candidate method specification for $PM_{10}$. Note that as after 313 days there were only 4 days where $PM_{10}$ was ≥30 µg $m^{-3}$, and so the decision was taken to stop the test in accordance with the requirements of the performance standard. Of these 313 days, 7 were excluded due to low data capture on either the Fidas (six days) or Kunak Air Pro (1 day).

**Table 7.1** Intra instrument uncertainties for the Air Pro for $PM_{10}$.

| **All Data** | | **<30 µg $m^{-3}$** | | **≥30 µg $m^{-3}$** | |
|---|---|---|---|---|---|
| **n** | **$u_{bs}$ / µg $m^{-3}$** | **n** | **$u_{bs}$ / µg $m^{-3}$** | **n** | **$u_{bs}$ / µg $m^{-3}$** |
| 306 | 1.74 | 302 | 1.74 | 4 | 2.47 |

The results are shown in Table 7.2. Calculations were performed on the 24 hour average data (after slope correction as explained in the following Section). For all three categories, the intra instrument uncertainty ($u_{bs}$) was lower than the required 5 µg $m^{-3}$, and as such, the instrument meets the Intra instrument uncertainty for the candidate method specification for $PM_{2.5}$. Note that after 313 days there were 14 days where $PM_{2.5}$ was ≥18 µg $m^{-3}$, which is more than the required 8 days.

**Table 7.2** Intra instrument uncertainties for the Air Pro for $PM_{2.5}$.

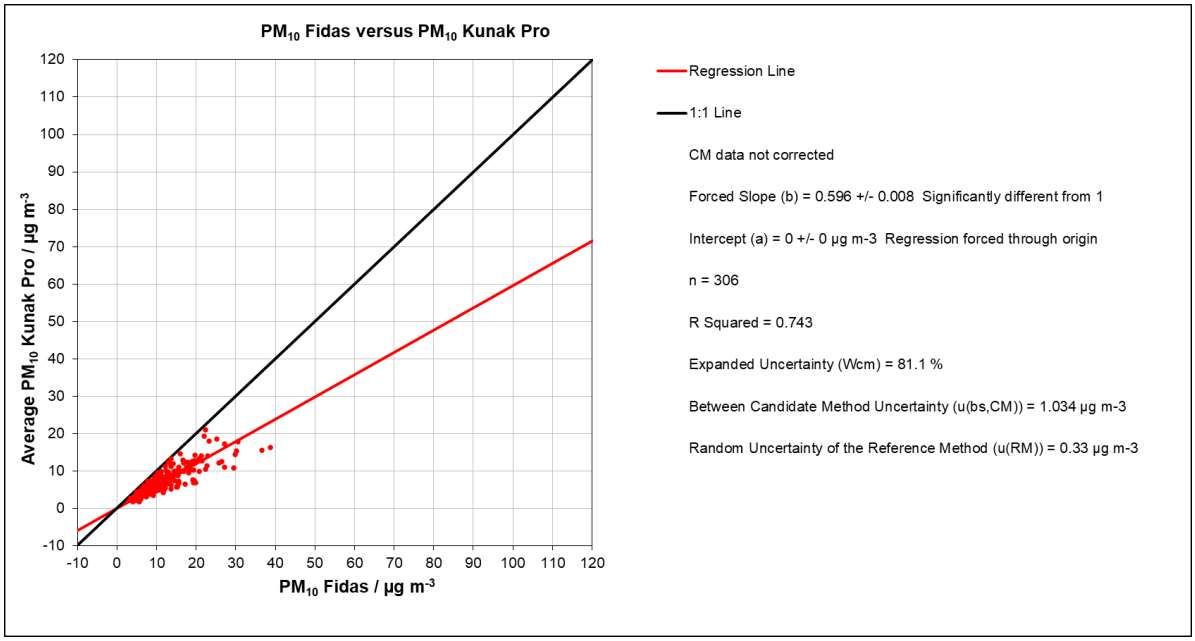
| **All Data** | | **<18 µg $m^{-3}$** | | **≥18 µg $m^{-3}$** | |
|---|---|---|---|---|---|
| **n** | **$u_{bs}$ / µg $m^{-3}$** | **n** | **$u_{bs}$ / µg $m^{-3}$** | **n** | **$u_{bs}$ / µg $m^{-3}$** |
| 306 | 0.81 | 292 | 0.75 | 14 | 1.64 |

# 8. Expanded Uncertainty of the Candidate Method for $PM_{10}$

The performance standard states that the highest expanded uncertainty estimate ($W_{CM}$) should be below 50%. For $PM_{10}$, the expanded uncertainty is assessed for the full dataset, and the dataset split to be greater than 30 µg $m^{-3}$. Of the full dataset at least 8 pairs of the results obtained by employing the standard method must be greater than 30 µg $m^{-3}$. If 80 data pairs are produced still without generating the required 8 data pairs in the "greater than" subset then this is considered sufficient and the testing may be terminated. In accordance with the performance standard, the expanded uncertainties were calculated at 50 µg $m^{-3}$ using the methodology described in EN16450[4].

The 24 hour average $PM_{10}$ Air Pro data were calculated from the 5 minute raw data. The 24 hour averages of instruments 0321180036 and 0321180037 were then averaged. These were plotted against the 24 hour average of the $PM_{10}$ Palas Fidas 200 Equivalent Method data (Figure 8.1). Of the 313 days, 7 were exculded due to low data capture/ratification, leaving 306 remaining. It was decided to use orthogonal regression forced through the origin, which is permitted according to the performance standard.

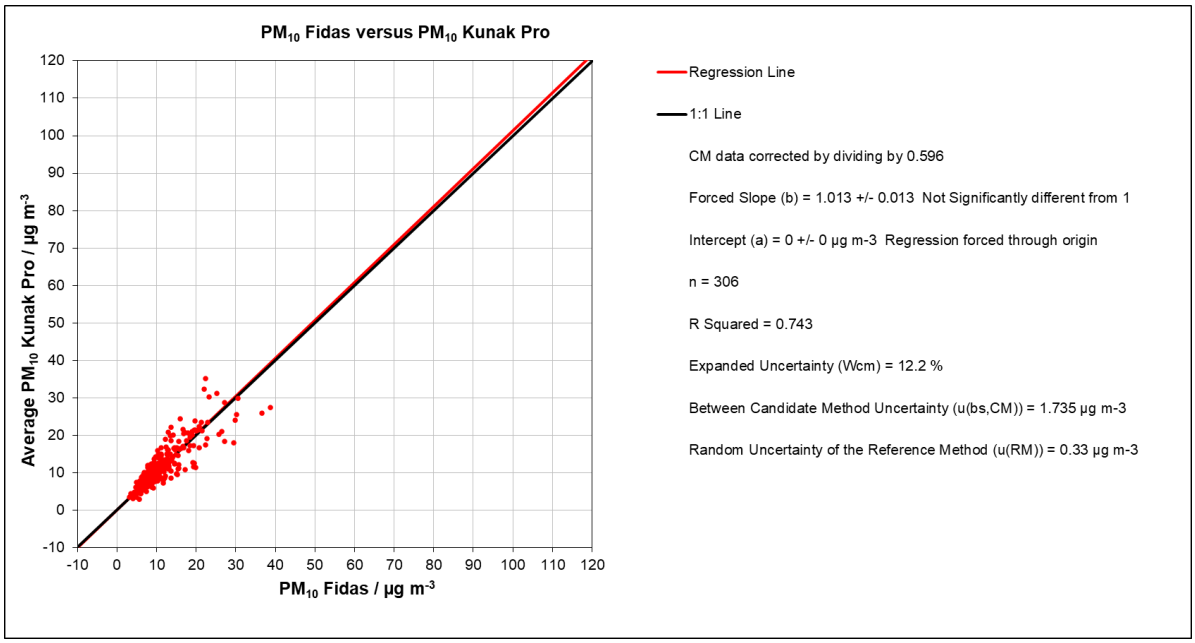
**Figure 8.1** Comparison of 24 hour averages of $PM_{10}$ Air Pro against the $PM_{10}$ Palas Fidas 200.




The figure gives the slope (b); intercept (a); number of data points (n); $R^2$; the expanded uncertainty ($W_{CM}$); and the between candidate and reference method uncertainties discussed in the previous two sections. The expanded uncertainty is 81.1% which is above the required 50%.

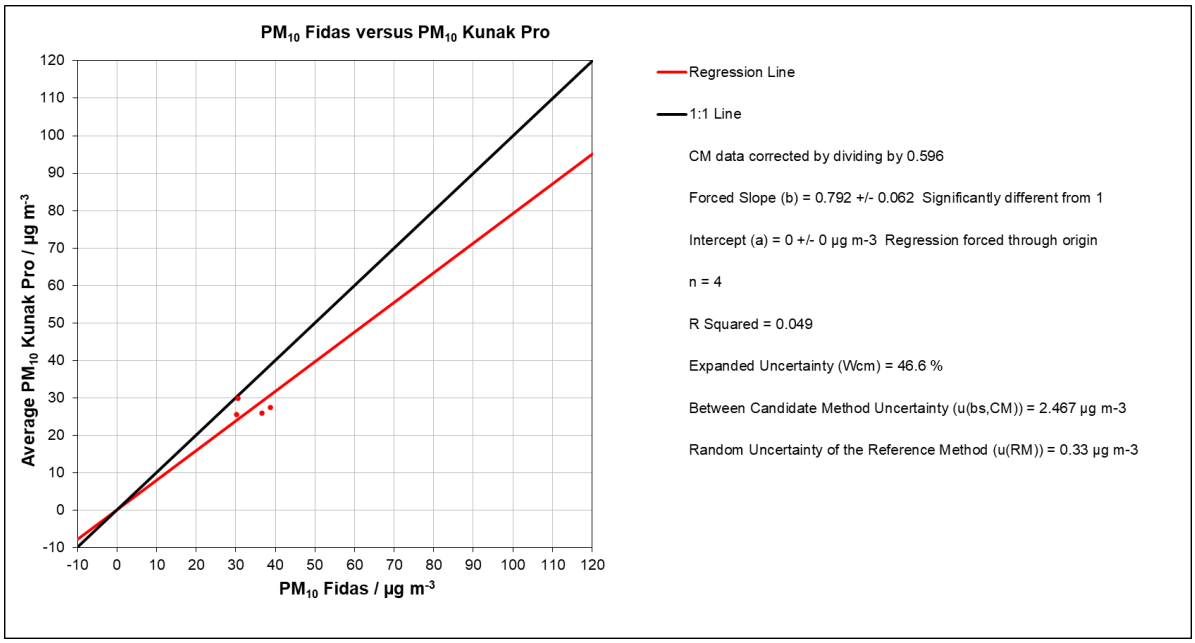
The Air Pro data were corrected by dividing by the slope of 0.596 and these data are shown in Figure 8.2. The expanded uncertainty is 12.2% which is below the required 50%.

**Figure 8.2** Comparison of 24 hour averages of $PM_{10}$ Air Pro against the $PM_{10}$ Palas Fidas 200 slope corrected by dividing by 0.596.




The four points where $PM_{10}$ was ≥30 µg $m^{-3}$ are plotted in Figure 8.3 again after slope correction by dividing by 0.596. The expanded uncertainty is 46.6% which is below the required 50%.

**Figure 8.3** Comparison of 24 hour averages of $PM_{10}$ Air Pro against the $PM_{10}$ Palas Fidas 200 slope corrected by dividing by 0.596. ($PM_{10}$ ≥30 µg $m^{-3}$)

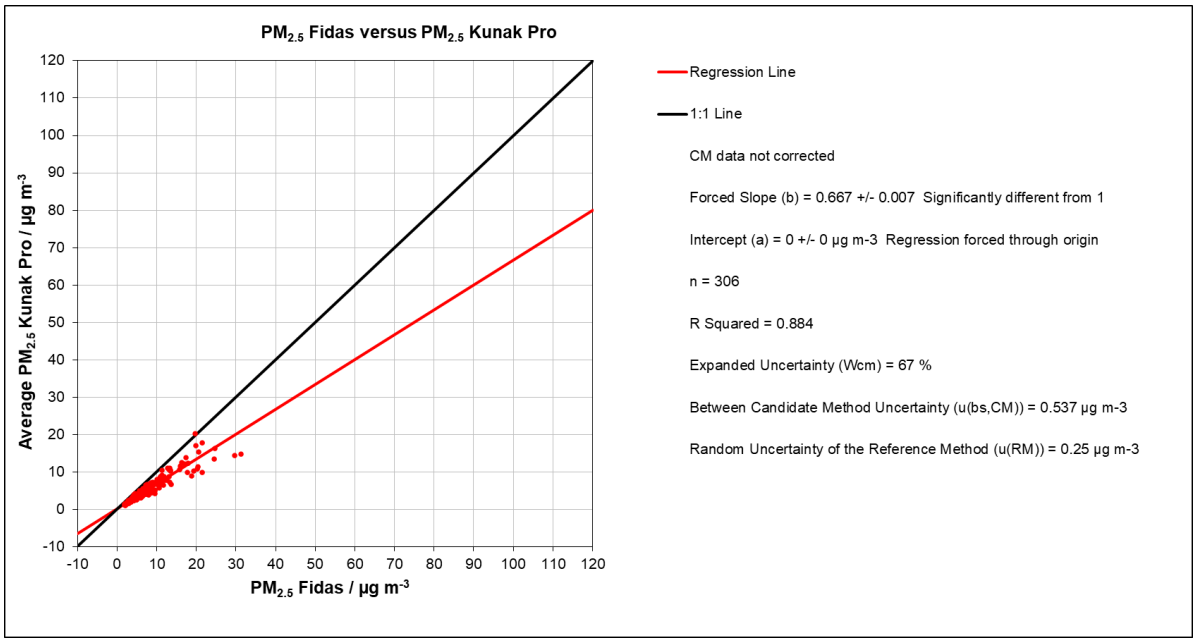


# 9. Expanded Uncertainty of the Candidate Method for $PM_{2.5}$

The performance standard states that the highest expanded uncertainty estimate ($W_{CM}$) should be below 50%. For $PM_{2.5}$, the expanded uncertainty is assessed for the full dataset, and the dataset split to be greater than 18 µg $m^{-3}$. Of the full dataset at least 8 pairs of the results obtained by employing the standard method must be greater than 18 µg $m^{-3}$. If 80 data pairs are produced still without generating the required 8 data pairs in the "greater than" subset then this is considered sufficient and the testing may be terminated. In accordance with the performance standard, the expanded uncertainties were calculated at 30 µg $m^{-3}$ using the methodology described in EN16450[4].

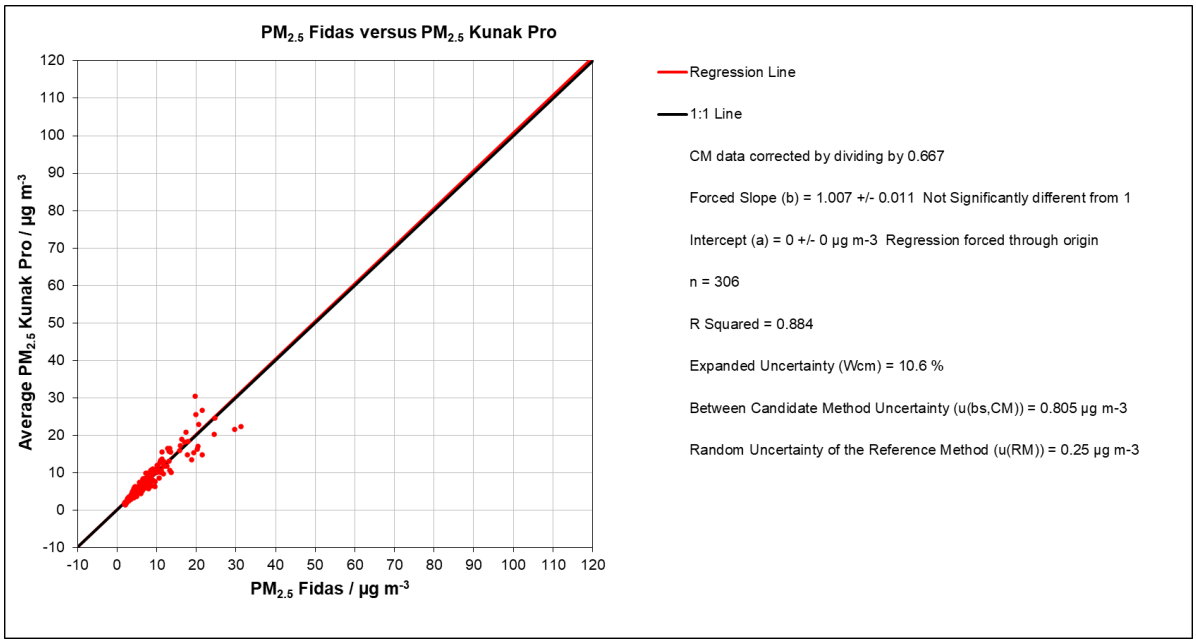
The 24 hour average $PM_{2.5}$ Air Pro data were calculated from the 5 minute raw data. The 24 hour averages of instruments 0321180036 and 0321180037 were then averaged. These were plotted against the 24 hour average of the $PM_{2.5}$ Palas Fidas 200 Equivalent Method data (Figure 9.1). It was decided to use orthogonal regression forced through the origin, which is permitted according to the performance standard. The $PM_{2.5}$ Palas Fidas 200 data have been divided by 1.06, as is required as a result of the initial equivalence test of the instrument. The expanded uncertainty is 67.0% which is above the required 50%.

**Figure 9.1** Comparison of 24 hour averages of $PM_{2.5}$ Air Pro against the $PM_{2.5}$ Palas Fidas 200 (All data).



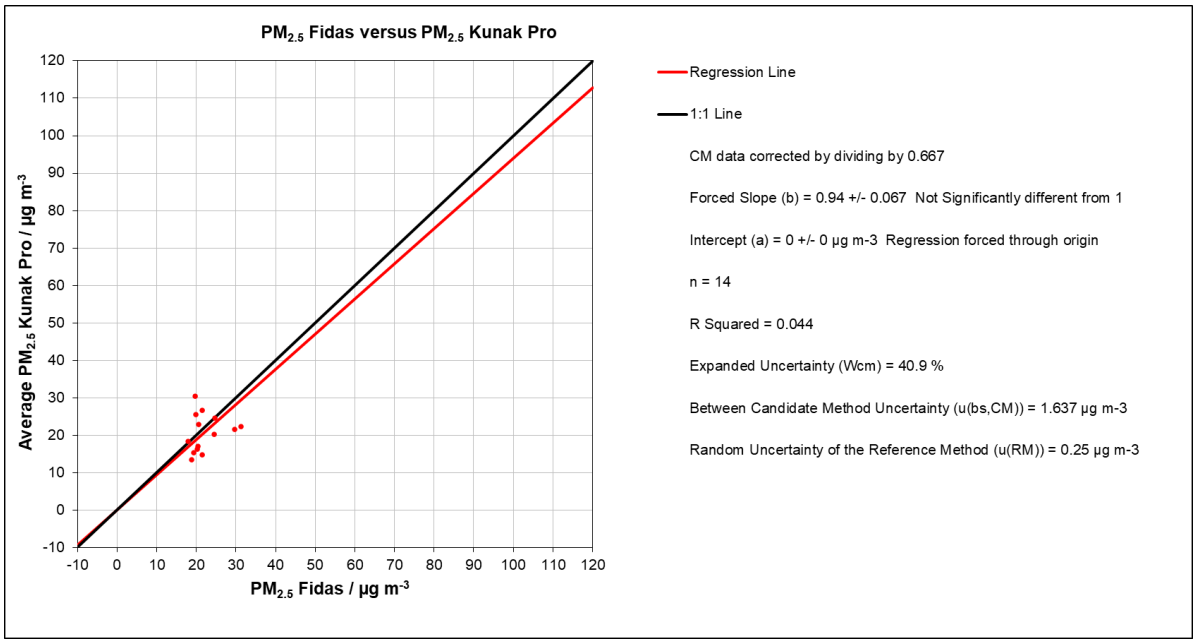
The Air Pro data were corrected by dividing by the slope of 0.667 and these data are shown in Figure 9.2. The expanded uncertainty is 10.6% which is below the required 50%.

**Figure 9.2** Comparison of 24 hour averages of $PM_{2.5}$ Air Pro against the $PM_{2.5}$ Palas Fidas 200 slope corrected by dividing by 0.667.




The 14 points where $PM_{2.5}$ was ≥18 µg $m^{-3}$, are plotted in Figure 9.3 again after slope correction of dividing by 0.667. The expanded uncertainty is 40.9% which is below the required 50%.

**Figure 9.3** Comparison of 24 hour averages of $PM_{2.5}$ Air Pro against the $PM_{2.5}$ Palas Fidas 200 slope corrected by dividing by 0.667 ($PM_{2.5}$ ≥18 µg $m^{-3}$).



# 10. Maintenance Interval

The performance standard states that the maintenance interval should be a minimum of 2 weeks. During the 44 weeks that the instruments were operational at Manchester University Fallowfield, no maintenance was required. The manufacturer recommends that users clean the PM inlet if it becomes dirty. If a problem arises, such as sensor malfunction or obstruction, then the software will detect it automatically and will invalidate the measurements and advise the user to carry out specific maintenance. It is further recommended to change the PM sensor after 2 years operation. As this required maintenance procedures is at a frequency of greater than 2 weeks frequency, the instrument passes this criterion.

# 11. Conclusions

The Kunak Air Pro Monitor passes all of the criteria set out in the Performance Standard for indicative instruments Version 4 for collecting $PM_{10}$ and $PM_{2.5}$ data when operated with algorithm KAIR_OPCN3_30. Kunak have made the decision to automatically slope correct $PM_{10}$ data by dividing 0.596 and slope correct $PM_{2.5}$ data by dividing by 0.667. These changes are incorporated in Firmware version KAIR_OPCN3_31. Therefore users should not make these additional corrections.