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Short communication

Evaluation of TEOM™ 'correction factors' for assessing the EU Stage 1 limit values for PM10

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Abstract

A study has been carried out to compare the results of PM10 determinations using TEOM™ and gravimetric instruments. Whilst the TEOM instruments have been used by the UK Government for many years to develop a National Air Quality Objective, the European Directive (99/30/EC) Stage 1 limit values for PM10 require a gravimetric method (or an approved equivalent method) to be used. However, there are significant differences between the two techniques, which have been investigated by co-locating a TEOM PM10 monitor and a gravimetric (Partisol) PM10 sampler at Marylebone Road, London between June 1997 and January 2000. This paper investigates the current practice of using a single 'correction factor' on TEOM PM10 data when these data are being used to assess the EU Stage 1 limit values for PM10, which should be measured using a gravimetric technique. The ability of the 'corrected' TEOM PM10 values to accurately reflect the annual mean and the number of 24 h means above 50 $\mu g\,m^{-3}$ produced by the co-located Partisol PM10 sampler is used as the test for the suitability of the single correction factor. This study demonstrates that a single 'correction factor' will not reflect the site and season specificity.

Keywords: PM10 monitoring; Gravimetric; Partisol; Limit values; TEOM

1. Introduction

The UK Government set up an Expert Panel Air Quality Standards (EPAQS) that examined evidence from epidemiological studies from UK, Europe and the USA and concluded that there was a causative link between particulate air pollution and certain indices of ill-health (EPAQS, 1995).

The comparison between the TEOM™ instrument and the gravimetric Partisol instrument was undertaken as part of a wider programme at the Marylebone Road cabin comparing continuous and non-continuous techniques. The TEOM has been used by the UK Government for many years as it records real-time mass concentration measurements allowing analysis of diurnal trends and the ability to track the passage of pollution episodes. The Partisol is a gravimetric filter sampler as required by the European Directive (99/30/EC) Stage 1 limit values for PM10.

This paper explores the relationship between the TEOM PM10 measurements and those from a co-located Partisol PM10 sampler. The correlation between these methods for mass measurement has been explored by many studies (Salter and Parsons, 1999; APEG, 1999; Allen and Reiss, 1997; Smith et al., 1997), which assign differences to the 50°C sampling conditions employed by the TEOM and the subsequent volatilisation of a portion of the PM10. Therefore, the magnitude of the discrepancy depends on the amount of material in PM10 that is volatile at 50°C, which is expected to vary both temporally and geographically. It has also been suggested that the relationship between TEOM and Partisol instruments is curvilinear due to the loss of volatile species by the TEOM that characterise periods of high PM10 concentration around the UK (APEG, 1999). It should be noted that gravimetric samplers also have the potential to lose some volatile species, depending on the sampling duration and the environmental conditions that the

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filter is exposed to during sampling and prior to weighing.

The UK Government has undertaken PM10 measurements using TEOMs for a number of years and developed a National Air Quality Strategy Objective using the results of epidemiological studies based on TEOM data (APEG, 1999). However, the UK Government has recently replaced the National Air Quality Strategy Objective with the EU Stage 1 limit values for PM10 (DETR, 2000). These new limit values require PM10 to be measured using a method which has shown equivalence to the European transfer gravimetric method. Consequently, the UK Government has started a national monitoring programme to provide the information required to demonstrate the degree of equivalence between these two methods.

Until the data from this monitoring programme are reported, local authorities in the UK have been advised to apply a 'correction factor' to the results of their TEOM PM10 monitoring; multiplying by a factor of 1.3 when assessing the likelihood of areas exceeding the EU limit values (DETR, 1999). This factor was derived from previous co-location studies in the UK, which concluded that TEOM instruments underestimated the Partisol PM10 by 15–30% at concentrations around the air quality standard of $50\,\mu g\,m^{-3}$ (APEG, 1999).

This article addresses three key issues surrounding the use of 'correction factors' when assessing the EU Stage 1 limit values:

1. *Geographical variability*. Several studies have been carried out in a range of locations in the UK. These studies have produced regression equations that describe the relationship between the two methods and are used to assess the effect of applying 'correction factors' from one location in another.
2. *Curvilinear regression equations*. Equations containing polynomial or power functions are used as 'correction factors' to investigate whether these may better reflect the curved nature of the relationship between the two methods.
3. *Temporal variability*. The long-term data set available from Marylebone Road has allowed an investigation of the seasonal and annual variations in this relationship over $2\frac{1}{2}$ years.

The importance of each of these issues is illustrated by considering its implications for equating the TEOM result to a gravimetric measurement for use in assessing the EU limit values.

The measurements for this study were undertaken in a cabin on the Marylebone Road, this is a major route in and out of Central London, running north-east to south-west and carries approximately 90,000 vehicles per day. The tall buildings on either side form a broad street canyon ~ 40 m across. The monitoring cabin is located 1 m from the kerb on the southern side of the road. A wide range of monitoring has been undertaken at this location since June 1997, and the continuous gaseous and particulate matter measurements are reported routinely as part of the London Air Quality Network and the UK Government's Automatic Urban Network (AUN) (DETR, 1999).

2. Method

Measurements were made at the Marylebone Road AUN site between June 1997 and January 2000. The sampling locations were all 1 m from the kerb. Both methods use a Rupprecht & Patashnick supplied PM10 inlet with a flow of $16.7\,l\,min^{-1}$. The TEOM 1400AB (Rupprecht & Patashnick Co) diverts $3\,l\,min^{-3}$ of the flow from the PM10 inlet to a 16 mm PTFE-coated glass fibre filter that is positioned on a tapered glass element. The sampling stream and filter are heated to 50°C to maintain a stable temperature and eliminate interference from water on the filter. The mass measurement relies on the measurement of the resonant frequency of an oscillating system that consists of the filter and glass element. The TEOM was operated at default settings, although, mass concentration averaging time and logging interval were adjusted to 900 s. Data was reported at the US EPA STP of 25°C and 1 Atm, correcting for local temperature and pressure. The TEOM is operated as part of the AUN and benefits from extensive quality control procedures; the calibration factors and flows are checked by the National Physical Laboratory every 3 months.

The Partisol 'Starnet' System (Rupprecht & Patashnick Co) comprises a hub and three stations (satellites). The hub unit contains the pump, solenoids and flow control unit which allow switching between the satellites on consecutive days. All sampling units are located within the cabin which is maintained at 20°C, this is identical to the filter conditioning temperature, therefore there will be no further volatalisation of the particulate matter.

The particulate matter is deposited onto a pre-weighed 47 mm PTFE filter which is removed for weighing at the end of the sampling round (every 3 days). The filters are equilibrated in the laboratory for 24 h before and after exposure, prior to weighing, using an A & D Instruments HM202 balance. The weighing conditions during the study were monitored in the range 50($\pm$10)% relative humidity and 20($\pm$5)°C. Tests undertaken to assess the variability of filter weights showed no change in filter weight up to 60% relative humidity.

Daily means (midnight to midnight) were used to compare the two techniques, using a total of 430 data points. Initially samples were taken on a daily basis, however, during the last 15 months of this study samples were taken on alternate days.

The EU Stage 1 limit values for PM10, which should be measured using a gravimetric technique, are

Table 1
Geographical variations in the linear regression equations resulting from their use as 'correction factors'

Instrument	Slope	Intercept	r	24 h means greater than $50\,\mu g\,m^{-3}$	1998 annual average ($\mu g\,m^{-3}$)	1999 annual average ($\mu g\,m^{-3}$)
Partisol				81	38	39
TEOM				28	33	32
'Corrected' TEOM results						
1.3 Correction factor	1.30			121	43	42
Marylebone Road	1.33	− 5.14	0.91	71	39	38
Cornwall (Salter and Parsons, 1999)	1.55	− 6.09	0.94	156	45	44
Ribble Valley (DETR, 1999)	1.15	− 0.05	0.92	63	38	37
South Yorkshire (DETR, 1999)	1.30	0.00	0.89	121	43	42
Greenwich (Smith et al., 1997)	1.76	− 13.15	0.98	160	44	43

$40\,\mu g\,m^{-3}$ as the annual mean and $50\,\mu g\,m^{-3}$ as a fixed 24 h mean not to be exceeded more than 35 times per year. The ability of the 'corrected' TEOM PM10 values to accurately reflect both the annual mean and the number of 24 h means above $50\,\mu g\,m^{-3}$ produced by the co-located gravimetric instrument, is used as the test for the suitability of the correction factor. The regression equations produced by correlating the two techniques are used as the 'correction factors' and applied to the Marylebone Road TEOM PM10 data. In all the regression equations the TEOM is the dependent variable and the Partisol the independent.

3. Results and discussion

3.1. Geographical variability

Several previous studies (Salter and Parsons, 1999; APEG, 1999; Smith et al., 1997) have derived regression equations describing the relationship between a TEOM PM10 and Partisol PM10 sampler. Each of these regression equations has been applied as a 'correction factor' to the Marylebone Road data set and is shown in Table 1.

The 1.3 'correction factor' suggested by the UK Government overestimates the number of exceedences of the 24 h mean as measured by the Partisol by 50% and the annual averages by 13% for 1998 and 8% for 1999. If a similar overestimation is experienced in other locations it will lead to substantial policy implications for local and national governments. The variation between the regression functions from different locations in the UK reflects the different sources and composition of PM10 that is volatile at 50°C and will determine the magnitude of the discrepancy between the two techniques. For example, the Cornwall monitoring was heavily influenced by china clay works (Salter and Parsons, 1999) and the Ribble Valley monitoring has some influence from industrial sources (APEG, 1999). The regression equation provided by Smith et al. (1997) was the result of monitoring during 1995–1996 in a suburban location in London. These locations contrast with the heavily trafficked kerbside location for the Marylebone Road monitoring. One factor is therefore unlikely to be practical for 'correcting' TEOM PM10 data from all locations.

3.2. Curvilinear regression equations

Linear regressions are used to analyse the data produced by the TEOM and Partisol instruments, however they produce a negative intercept due to the divergence of the results at higher concentrations. Salter and Parsons (1999) produced a non-linear regression that had a higher regression coefficient than the corresponding linear regression.

Linear, polynomial and power regression equations resulting from analysing the Marylebone Road data are shown in Table 2. Although the divergence of the two techniques at higher concentrations may be better described by curvilinear regressions, their use made no improvement on the 'correction' of the TEOM data for comparison to the EU limit value. The TEOM measurements in the 30–$50\,\mu g\,m^{-3}$ range will have the greatest impact on the 24 h EU limit values and it is the ability of the regression equation to accurately 'correct' these values which will determine its suitability.

3.3. Temporal variability

Results from the $2\frac{1}{2}$ year period have been examined seasonally (winter being October to March and summer being April to September) and annually (for the calendar years 1998 and 1999 only). Linear and polynomial regression equations have been produced, which are shown in Table 3.

Winter episodes are characterised by inversions leading to a build up of pollution from local sources. These lead to a more linear relationship because the relative

Table 2
Different regression equations and the result of their application as TEOM 'correction factors' for Marylebone Road

Instrument	Function	r	24 h means greater than 50 $\mu g\,m^{-3}$	1998 annual average ($\mu g\,m^{-3}$)	1999 annual average ($\mu g\,m^{-3}$)	Maximum ($\mu g m^{-3}$)
Partisol			81	38	39	116
'Corrected' TEOM results						
Linear regression	$y = 1.33x - 5.14$	0.92	71	39	38	109
Polynomial regression	$y = 0.0052x^2 + 0.91x + 2.44$	0.92	68	39	38	119
Power	$y = 0.84x^{1.092}$	0.92	67	38	37	108

Table 3
Seasonal and annual regression equations for Marylebone Road

	Equation	r
Summer	$y = 1.28x - 4.03$	0.84
Winter	$y = 1.35x - 5.07$	0.93
Summer	$y = 0.027x^2 - 0.53x + 24.09$	0.86
Winter	$y = 0.0019x^2 + 1.19x - 2.39$	0.93
1998	$y = 1.39x - 7.19$	0.92
1998	$y = 0.0102x^2 + 0.652x + 4.9029$	0.92
1999	$y = 1.34x - 4.73$	0.91
1999	$y = 0.0043x^2 + 0.9885x + 1.9122$	0.90

composition of PM10 will not change as much during the summer.

Summer conditions are more complex, containing a substantial proportion of secondary particulate matter due to photochemisrty. This particulate matter comprises volatile species such as ammonium nitrate, ammonium sulphate as well as an organic fraction (APEG, 1999). Volatalisation of some of this secondary component leads to a large divergence between the two methods at a range of PM10 concentrations. The greater difference between the TEOM and Partisol instruments over a range of concentrations during photochemical conditions results in lower r values. However, this analysis cannot differentiate between the volatile fraction from local sources and secondary particulate matter. During photochemical episodes the volatile species make up a larger proportion of PM10 at higher concentrations resulting in the more curved polynomial regression equation.

Both the linear and polynomial regression equations have been used as 'correction factors' for the TEOM data. These factors have been applied to either each relevant season over the entire monitoring period or to each relevant year (1998 and 1999); the results are shown in Tables 4 and 5.

Table 4
Seasonally applied 'correction factors'

Instrument	24 hour means greater than 50 $\mu g\,m^{-3}$	1998 annual average	1999 annual average
Partisol	81	38	39
Seasonally 'corrected' TEOM results			
Linear regressions	75	39	38
Polynomial regressions	71	38	38

Table 5
Annually applied 'correction factors' for the calendar years 1998 and 1999

Instrument	24 h means greater than 50 $\mu g\,m^{-3}$	1998 annual average	1999 annual average
Partisol	63	38	39
Annually 'Corrected' TEOM results (1998 and 1999)			
Linear regressions	62	38	38
Polynomial regressions	55	38	39

Using either type of 'correction factor' derived and applied seasonally or annually has resulted in better agreement than when the single 'correction factor' is applied. The linear regression derived from each season or year results in the best agreement between the two techniques.

The seasonal effect may be more marked at other locations. The PM10 concentrations measured at Marylebone Road are amongst the highest in the UK and show a greater proportion of PM10 from local sources (APEG, 1999). Other locations, where concentrations are lower, will be affected to a greater extent by changes in the secondary particulate matter concentration. The degree of seasonal variability may also change on a yearly basis depending on meteorological conditions. Therefore, any 'correction factors' applied to TEOM data should incorporate the local geographical and temporal variability .

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