行政院及所屬各機關出國報告

（出國類別：實習）

（裝訂線）

煙氣排放監測模式相關技術及營運管理體系

服務機關：台灣電力公司
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出國地區：美國
出國日期：九十一年十二月五日至
九十一年十二月十八日
報告日期：九十二年二月十四日

行政院及所屬各機關出國報告提要

出國報告名稱：煙氣排放監測模式相關技術及營運管理體系研習

頁數 38 含附件：■是□否

出國計畫主辦機關/聯絡人/電話　台灣電力公司人事處/陳德隆/(02)2366-7685

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關鍵詞：PEMS、CEMS、煙氣排放模式、煙氣監測技術

內容摘要：(二百至三百字)

本公司過去十餘年來已在各火力電廠建立連續排放監測系統(CEMS，Continuous Emission Monitoring System)，可利用過去累積之大量 CEMS 監測資料為基礎，運用統計學及燃燒學理論，並結合資訊及通訊技術，選擇適當機組推導建立完備之煙氣排放模式 PEMS (Predictive Emission Monitoring System)，預測其排放狀況，以取代機組原有之 CEMS 監測系統。

本實習主要係針對 PEMS 煙氣排放模式技術研發近況、美國 PEMS 相關法規及案例說明、PEMS 模式建置技術及軟硬體設備、品保品管制度以及相對準確度測試等技術加以研討，冀藉此提昇本公司建置火力電廠發電機組 PEMS 模式系統之技術能力，有助於本公司將來向環保主管機關爭取認可，以 PEMS 模式做為煙氣標準監測方法，俾節省大量煙氣監測費用，減少電廠營運成本，提高公司經營績效。

本文電子檔已傳至出國報告資訊網(http://report.gsn.gov.tw)

目錄

壹、報告人：陳國琨

貳、出國任務：煙氣排放監測模式相關技術及營運管理體系

參、出國期間：九十一年十二月五日至九十一年十二月十八日，共計十四天。

肆、國外公務之內容與過程：

一、十二月五日至十二月六日：路程，台北→西雅圖→紐約→阿巴尼。

二、十二月六日至十二月十六日：至美國環保署認可的紐約茹普瑞克公司(RUPPRECHT AND PATASHNICK)拜會艾瑞克(Erich Rupprecht)先生，並由該公司安排瞭解固定污染源中懸浮微粒粒徑小於 10 微米之懸浮微粒目前環境偵測情形及前瞻性以及煙氣排放監測模式相關技術及營運管理體系，屆時參觀奧斯吉藭(Arthur Kill)氣渦輪機及儀器廠家瞭解其在煙氣排放監測模式相關技術及營運管理體系之運用情形，最後作整體性討論，並結束此研習課程。

三、十二月十六日至十二月十八日：路程，阿巴尼→紐約→西雅圖→台北。

伍、國外公務之心得與感想：

一、前言

行政院環境保護署為確實掌握大型污染源的空氣污染物排放情形，已於民國 82 年起依據空氣污染防制法第二十一條訂定「固定污染源空氣污染物連續自動監測設施管理要點」及相關之品保品管技術規範，並於民國 91 年公告應設置空氣污染物連續自動監測設施(Continuous Emission Monitoring Systems, 簡稱 CEMS)之固定污染源，建立完整之煙氣監測體系。CEMS 系統實施多年來其測值已廣泛應用於空氣污染之管制及規劃，並作為徵收空污費之依據以及空氣品質惡化緊急應變時計算減量大小，成效顯著。

純就環境監測而言，國內外在 CEMS 技術方面已累積有相當豐富的建置及操作經驗，然就國內外截至目前為止的運作經驗得知，CEMS 之耗費甚為龐大，一套完全符合標準之連續排放監測系統裝設費就高達十五至三十萬美元，在正式操作運轉前須執行各種檢測以通過認證，使用單位除須負擔耗材零件備品之更換、定期保養、故障檢修外，並須定期執行各種檢測，諸如相對準確度測試稽查、相對準確度稽查和標準氣體稽查等以確保測值之準確，對使用單位而言實是一筆不小的支出與工作負擔，因而促使業者轉而尋求其它較經濟較便利的替代監測技術。

自 1980 年初期即有針對某些排放情形穩定的污染源（如燃用天然氣之氣渦輪機組）運用燃燒原理或統計模式以預測其污染物排放情形之構想，並進行研發，此種監測技術通稱為預測型連續排放監測系統(Predictive Emission Monitoring System，簡稱 PEMS)，目前在美國、瑞典、澳洲和印度已有將 PEMS 應用於發電廠、紙廠、化工廠、天然氣輸送加壓站等之實例。

美國早在 1990 年公告修訂之清淨空氣法修正案(CAAA)已將 PEMS 納入，但在 1994 年以前 PEMS 系統因為無法準確地預測排放濃度，不易為環保主管機關所接受，嗣經有關單位多年的研發努力，截至目前為止，在美國已有超過 200 組以上的排放設備建置 PEMS 系統且已被環保主管機關所接受認可，頗具實用前景。

此次研習與國外相關機構建立有效之聯繫管道，便於資料交換及技術合作，對其 PEMS 技術、法規標準之最新進展作深入瞭解，引進所需之技術、管理及品保品管制度等，以建立本公司之 PEMS。並與國外相關機構建立有效之聯繫管道，便於資料交換及技術合作，使本公司之環境監測技術與先進國家同步。

此行著重於瞭解替代 CEMS 之功能，到底可節約儀器設置、維修、檢測等的成本情形。於 CEMS 故障失效時作為替代之監測措施時，至少可提高監測資料之獲

取率，並提供環保機關在認可時之參考，未來可考慮逐漸推廣至本公司其他機組。另可將此一技術提供其他民營發電業者，或其他事業機構運用，獲取研發收益。最後期待與世界先進國家同步推動，建立本公司之技術能力，提升聲譽及民營化後之競爭力。

二、考察期間相關見聞

(一) 參觀紐約茹普瑞克公司

美國對於一特定地區的有害污染物(toxic air pollutants)感興趣及關心已有很多年了，近年來已能充分使用接收量測儀器來量測污染源排放至大氣中之基本成份。而對人體健康影響的評估主要掌控於聯邦、州政府及地方政府所蒐集到的這些污染源排放至大氣中基本成份的資料。若要有一正確的評估，最基本的要求則是這些污染源的量測資料是由正確的量測而來的。

在大氣中懸浮微粒物質（Suspended particulate matter ，SPM)是一複雜、多相系的空氣組成，可能是一固體及低蒸氣壓液體微粒，具有氣態相，微粒大小從 0.01 µm 至 100 µm 或更大。過去懸浮微粒物質的量測集中在總懸浮微粒（total suspended particulates ，TSP)，而?有特定大小之選擇。

美國環保署(USEPA)總懸浮微粒量測參考方

法是列在 40 CFR 50,Appendix B. 此方法是使用一大體積（high-volume）取樣器來收集氣態小於 100 μm 或更小的微粒。這大體積空氣取樣其取樣週期中是以每分鐘 40 或 60 立方英尺的固定取樣速率, 此大體積取樣使得 TSP 均勻地經過濾紙而沉澱在取樣器口下方的濾紙表面上, 這 TSP 含量在一段蒐集取樣週期後作為平均 TSP 含量，之後再分析 TSP 內的無機金屬量。

研究大氣中 TSP 對健康的影響已逐漸著重在這些微粒那些會進入呼吸系統, 例如氣態微粒小於 10 μm，研究學者一般認為這些氣態微粒小於 10 μm 可能造成人體健康顯著、負面的影響。

在 1987 年 7 月 1 日美國環保署對於懸浮微粒有一新的定義對於微粒直徑小於<10 μm（PM_{10}）來區分原有的 TSP 標準，而於這些微粒 PM_{10} 的量測濃度有一新的聯邦參考方法（federal reference method，FRM)，此方法是基於粒徑分佈分離及移去非 PM_{10} 微粒，經由過濾及重力分析 PM_{10} 微粒。

監測懸浮微粒方法則列於 40 CFR Part 53 於 1987 年增修 PM_{10} 特定需求、參考方法及對等方法等。PM 10 的量測原理及符合其他規範則列於 40 CFR 50, 附錄 J。當然也含括了取樣週期、

取樣速率、儀器校正、濾紙媒介特性、過濾條件、濾紙重量、取樣操作、取樣體積修正在環保署參考之溫度壓力等等均列入增修條例中。

茹普瑞克公司的 TEOM®(Tapered Element Oscillating microbalance)連續監測方法中計

算物質速率、物質濃度及全量累積在可變的濾紙卡帶上等等皆經過許多專家學者的審議評估後很榮幸地被陳述美國環保署的方法論中。

此次筆者榮幸地被茹普瑞克公司艾瑞克(Mr. Erich Rupprecht)先生邀請來參加此訓練課程，藉此機會多瞭解美國環保署極力關注大氣中懸浮微粒對人體健康之影響，目前仍著重於 PM_{10} 的研究與發展及資料庫之建立，並加以分析整理研究，但未來將更著重於 $PM_{2.5}$ 的研究與發展，茹普瑞克公司也積極地從事此方面學理、精密儀器等之發展。

此次前來美國研習的主要重點則在預測型連續排放監測系統(PEMS)技術的探討，國外許多研發機構、鍋爐及儀器廠家近來已普遍對 PEMS 技術進行研發，運用統計學及燃燒學理論，並結

合資訊及通訊技術，對個別機組鍋爐建立排放模式，預測其排放狀況，以節約實際監測費用，並爭取政府環保機構之認可，茹普瑞克公司積極推展 TEOM ® Series 7000 煙道即時監測回饋系統作為 PEMS 用之儀器(詳如附錄)。本公司既已建立有 CEMS，可將過去累積之大量 CEMS 資料為基礎，並已選擇適當機組－興達複循環機組三號機及南火複循環機組一號機推導建立完備之 PEMS，目前本計畫已告一階段，因此派員至美國阿巴尼茹普瑞克公司，對其 PEMS 技術、法規標準之最新進展作一深入瞭解，未來期待能引進所需之技術、管理及品保品管制度等，期以對本公司目前之 PEMS 發展能有進一步之建言。並建立與國外相關機構之聯繫管道，便於資料交換及技術合作，使本公司之環境監測技術與先進國家同步。

還未前往美國之前也曾涉獵 PEMS 之規劃設置技術及營運管理體系研究計畫，單就相關法規層面來看，公公婆婆就一大堆，包括 1990 年空氣清淨法修正案中之 CAAA [2] section114 (a)(3)、section504 (b)，其後美國聯邦法規中之 40 CFR 51,52; [4] [5] [6]、40 CFR 64; [7]、40 CFR 60,75; [8] [9] [10]、40 CFR 70,71,72;

[11] [12] [13]、40 CFR 96,97; [14] [15]、40 CFR 63,266; [16] [17] [18] [19]、40 CFR 503 及 PS-16 草案等等，另外還有州政府及地方空氣品質區的相關法規等，已相當眼花瞭亂了，有點駐足不敢往前了，但回想一下，美國環保署為了人類福祉已投入這麼多心力，且已有許多實務經驗的廠家、學者、官方的文件可作前車之鑑，另外其他國家包括加拿大、澳洲、瑞典、日本、義大利等皆投入不少心力於此方面法規之訂定，國內未來的空氣防制法規也應慶幸 PEMS 技術的適法性與否，國外的法規可有得參考遵循之依據。

由於美國環保署於 1970 年代開始實施煙道連續監測之後，CEMS 所產生的操作及成本問題造成工業界業者們的負擔與困擾甚鉅，因此開始有人想到利用這些模式開發成本較低廉、操作較簡單的 NOx PEMS 法來取代，並在 1980 年代中期開始在氣渦輪機組(gas turbines)上進行測試，其結果似乎顯示 PEMS 可取代 CEMS，這個經驗加上 1990 年代在法規中列入條文、電腦科技的突飛猛進、通訊事業的發達，更促使 PEMS 的蓬勃發展。

以技術層面來看，整個 PEMS 的構想是透過

監測鍋爐、渦輪機之類的燃燒設施之操作參數，透過以熱力學或統計學為基礎的數學模式，由電腦程式加以預測，因此 PEMS 的組成包括大氣環境參數感應器、燃燒器(或渦輪機)控制參數感應器、安裝有預測軟體(以基本熱力學定律或統計學為基礎)之電腦系統、數據紀錄器。

對某些機組或排放源而言，其排放狀況可能極為穩定，甚少發生異常現象或造成污染的情形。例如燃用天然氣或含硫量極低燃油之發電機組，耗費鉅資執行監測而其測值幾無變化，測定硫氧化物即無甚意義。至於煙氣中之氮氧化物濃度與燃燒條件有關，似可以含氧率、煙氣流量、溫度等鍋爐操作條件或其特性推估而得，該類感測項目皆為鍋爐控制所必須且早已裝設者，故以 PEMS 執行監測可節省另行裝設污染物監測系統之費用。而美國聯邦、州與地方政府也在一些法令中(如 40CFR75)規定了一些替代方案或監測設施失控期間的數據補正方式。

但是就國內外截至目前為止的運轉經驗得知，CEMS 之耗費甚為龐大，一套完全符合標準之連續排放監測系統除了裝設費高達數十餘萬美元以上，在正式操作運轉前須執行各種檢測以

通過認證，使用單位除須負擔耗材零件備品之更換、定期之保養、故障之檢修外，並須定期執行各種檢測（相對準確度測試稽查(Relative Accuracy Test Audit, RATA)，相對準確度稽查(Relative Accuracy Audit, RAA)，標準氣體稽查(Cylindrical Gas Audit, CGA)等)以確保測值之準確，對事業機構而言係一筆不小的支出與工作負擔；而且採樣時易產生誤差、在惡劣環境中(如低溫或高溼度中)容易造成採樣困擾，在操作條件及大氣環境改變時，CEMS 反應較遲緩、且在進行每天校正偏移測試及其他維護保養工作時會有部分數據無法取得等缺點。

以成本層面來看，PEMS 技術有許多優點：

1)PEMS 技術已逐漸被許多合法的廠家包括美國環保署所接受。

2)一 PEMS 技術初始安裝及認證約須美金 70,000 至 125,000 元比起 CEMS 的硬體費約美金 150,000 至 300,000 元要便宜許多。

3) PEMS 的維護成本約美金 10,000 至 20,000 元比起 CEMS 的硬體維護費約美金 50,000 至 80,000 元要節省許多。

4)PEMS 技術已被證實一如 CEMS 的硬體一樣的正確。

5)感應器確認系統(Sensor Validation System)提供 PEMS 每分每秒的品質保證檢查且優於 CEMS 硬體的可信度。

6) PEMS 可能最重要地提供有價值的電廠營運資訊而 CEMS 的硬體僅提供排放資料；PEMS 技術能提供資訊去如何營運且最佳化的處理去完成最大輸出及最少的污染排放。

PEMS 技術亦有缺點：

1)許多工業官員們不願意去使用 PEMS，因為他們不能完全相信其準確度，不過這情形也已超過十年了，目前美國已有好幾百家安裝了 PEMS 且已然順利正常運作至今。

2)另一缺點是有一潛在性的衝擊…亦即在營運時之 PEMS 資料蒐集期間及認證事件上，在預定規劃期間亦應將此衝擊須列入成本計算，亦即避免產品有著負面的影響。

由以上之優缺點來看美國目前反到是業界在摧促環保署早點通過執行法案，過去由於經濟的不景氣，合法的業界已有 CEMS 硬體設備，但在一些法規上已讓業界不得不先採行 PEMS 技術。國內法規並未更動，以本公司已有 CEMS 硬體設備，而加裝 PEMS 控制設備是增加了成本，但也在此研究發展中吸取不少經驗，雖然目前的

CEMS 硬體設備已足夠符合環保法規之要求，但以長遠來看，公司長期營運外加維護成本考量及民營化之衝擊，實應儘早送請環保署參考修法，也對業界有著共同利益均享之思維而為之。

以前瞻性層面來看，PEMS 技術可透過先進的非線性迴歸曲線統計模式方式使得測值更加精確且能長期的監控污染源之排放。PEMS 的成本比 CEMS 硬體低的情況下，可由感應器確認系統(Sensor Validation System)的定期交叉檢查，來提高監測的精確度及可信度。PEMS 已漸漸地被廠家們所接受，並有取代 CEMS 的趨勢。另 PEMS 提供廠家低成本、低維護費、高可信度及更佳的控制技術，使廠家在營運時能有更好的效益且提供較低污染、更潔靜的環境。

(二) 參觀奧斯吉蘵(Arthur Kill)公司

Arthur Kill Generating Station
New York, New York USA

NRG 能源公司美國東北地區辦公室管轄下的奧斯吉蘵電廠位於紐約的史坦登島(Staten Island)有三部機組，是一天然氣/油發電廠，總發電量為 856 MW，奧斯偉峋(Oswego)發電廠為上紐約州最大之電廠，總發電量為

Oswego Generating Station – New York

1,700 MW，有二部天然氣/油發電機組。

電廠的環保政策皆是遵守當地環保法規，長期作煙氣排放監測的義務，使電廠對環境的衝擊減至最小，以維持地良好的空氣品質。

(三)本公司於 PEMS 技術之努力

本公司為了維護火力電廠鄰近地區之空氣品質，符合政府環保主管機關公告之各項政策與法令，在固定污染源的管制方面，有各種污染物的排放標準、設置/變更/操作排放許可證、專責單位與專責人員、煙道排放定期檢測以及設置/操作連續排放監測系統等等。其中，CEMS 具有即時、連續監測的功能，可使本公司及政府環保主管機關瞭解污染源排放情形 污染防治設施操作情況 計算空氣污染防制費以及空氣品質惡化緊急應變時計算減量大小。

但是就國內外截至目前為止的運轉經驗得知，CEMS 之所需之費用甚為龐大，一套完全符合標準之系統除了裝設費高達十餘萬美元，且在

正式操作運轉前須執行各種檢測以通過認證，使用單位除須負擔耗材零件備品之更換 定期之保養、故障之檢修外，並須定期執行各種檢測：相對準確度測試稽查(RATA)、相對準確度稽查(RAA)、標準氣體稽查(CGA)等，以確保測值之準確，對本公司而言係一可觀的支出與工作負擔；而且採樣時易產生誤差、在惡劣環境中(如低溫或高溼度中)容易造成採樣困擾、在操作條件及大氣環境改變時 CEMS 反應較遲緩、且在進行每天校正偏移測試及其他維護保養工作時將有部分數據無法取得……等缺點。

就某些機組或排放源而言，其排放狀況可能極為穩定，甚少發生異常現象或造成污染的情形，例如燃用天然氣或含硫量極低燃油之發電機組，耗鉅資執行監測而其測值幾無變化，其所代表之意義有限。而煙氣中之氮氧化物(NOx)濃度與燃燒條件有關，似可以含氧率、煙氣流量、溫度等燃燒爐操作條件或其特性推估而得，該類監測項目皆為燃燒爐控制所必須且早已裝設者，故近年來各先進國家逐漸研發 PEMS，對特定機組執行監測以節省裝設污染物監測系統之費用。

由於本公司近年來已逐漸增加氣渦輪、複循

環機組及 LNG 的使用，興達及南部發電廠已分別有五座及三座複循環機組完工運轉，該九部機組均為西門子同型機組，而未來大潭電廠亦可能有六至十二部同一型號之燃氣複循環機組，由於 1997 年京都議定書限制世界各國的 CO_2 排放量，未來勢必將逐漸增加氣渦輪、複循環機組及 LNG 的使用，因此有必要開發 PEMS 技術施於現有之燃氣機組。

以本公司現已建立之 CEMS 資料庫為基礎，在長期比較、分析及驗證確立其可行性後，應可研發出適用於本公司某些特定火力發電機組之 PEMS，並向我國環保署爭取認可，作為 CEMS 之替代系統，以達到降低監測費用、控制電廠營運成本之目的。

本公司 PEMS 研究案第一階段已選擇既有之燃氣發電機組進行實際測試，在興達發電廠之燃氣複循環機組一號機進行過一年之研究，主要工作項目為蒐集國外相關資料及實際經驗，並實地蒐集煙氣排放及相關運轉參數數據，推導 PEMS 模式等屬於可行性探討性質之先期研究，主要成果在於瞭解機組特性，解決機組運轉及監測儀器等不同數據訊號介面轉換及傳輸等問題，而建立

PEMS 模式所須之推導、驗證及修正之實測比對資料。

第二階段研究成果，除繼續蒐集興達發電廠之燃氣複循環機組一號機運轉操作數據之外，並在興達發電廠之燃氣複循環機組三號機與南部火力發電廠之燃氣複循環機組一號機各增設一部 PEMS 研發設施，以探討同一 PEMS 是否適用在同型但不同廠區之燃氣複循環發電機組；另外，針對興達發電廠之燃氣複循環機組一號機進行 RATA 測試，以驗證 PEMS 模式之準確度與精確性

目前已獲得之研發成果顯示 PEMS 具有技術可行性及經濟誘因，足以進行深入之模式研發及實地應用方式之探討，在獲得足夠資料足以涵蓋所有操作條件，並建構合理之品保品管程序後，可主動向環保主管機關申請認可。

第三階段之 PEMS 研發除持續在興達燃氣複循環一、三號機及南部電廠複循環一號機進行研究外，在南部電廠燃氣複循環一號機進行 RATA 檢測工作，同時以三部機組進行研發，作數據蒐集、PEMS 模式建立和預測的研究，預測項目則以 NO_x 及 O_2 為主，各機組及儀器運轉正常，操作時數亦維持一般水準時，可迅速累積充份之數

據資料，使建置完善之模式，並達到合理之準確性(既有 CEMS 之準確性須在以 80%上始符合法規要求)，其成果如下：

1.蒐集國外研究機構 燃燒爐及儀器廠家之技術資料，並對選定機組歷年之 CEMS 實測資料，運用統計學或燃燒理論，結合資訊與通訊技術，建立個別燃燒爐機組之排放模式。因此承辦本研究之機構其技術服務團隊須包括環境工程、燃燒學、資訊、儀控、統計學等不同專長，以統合各專業之能力完成 PEMS 技術之研發。

資料蒐集係針對現有特定機組蒐集其以往各種連續監測資料，包括污染物、負載量、燃料特性、燃燒爐特性(溫度、壓力、空氣流量、含氧率)、各項感應器之種類/數量/規格、目前 CEMS 之儀器規格/數據擷取與處理系統之型式等。

建立數學模式係運用各機組已有之各種資料(如燃燒爐型式)，以統計學方法或燃燒化學方法推導建立數學模式，其形態可能為一經驗公式，或一組適用於不同運轉條件之數學公式。目前已應用之 SAS 及 Excel 軟體及更

精密之軟體作模擬。

建立電腦應用系統係以個人電腦為主之硬體設備，軟體則採用國內自行編撰實用之電腦程式的方式。並安裝在相關機組上的感應器連接至此一電腦系統，蒐集即時之數據進行運算。

驗證測試係與煙氣之 CEMS 實測值（由台電既有設施取得）以及 RATA 檢驗結果（須由研究機構委託合格代檢機構辦理）相比較，分析其差異，將其修正至合理程度；且測試時之各項條件須週延，能涵蓋機組(排放源)運轉時所可能發生之各種情況。

模式修正係將初步建立之模式依驗證測試結果予以修正，可能增加或刪除某些參數，簡化該數學模式，便於運用，以免數學模式過於複雜，降低監測系統之效能。修正及驗證須反復執行，至誤差降至可接受程度為止。

配合本公司正向環保主管機關提出之 PEMS 管理要點(參照 CEMS 現行管理要點訂定)草案，包括技術規範、QA/QC 及認可驗證程序等資料，持續補充資料並作說明及展示，以及早獲得認可。

2.在研發期間經常與環保主管機關(環保署空保處、監資處、檢驗所等技術部門)及相關學者專家保持聯繫，獲取資訊及經驗並爭取認同，使成為標準監測方法期間，即早發現問題並加以解決，並順利通過主管機關之認可。

3.本公司在空氣污染物排放監測技術上一向居國內領導地位，台電公司環保處早於民國七十七年間即已引進美國聯邦環境保護署之CEMS 規範，率先規劃裝設監測系統，為當時(目前仍是)國內最大最完整之監測系統。嗣後行政院環境保護署制定之 CEMS 法規及技術規範時，即參照甚多有關台電之技術經驗，於八十二年間頒佈實施，國內所有大型排放源均須執行。而本 PEMS 研發案則在國內自行研發，與世界先進國家同步推動，在此一技術獲得認可成為標準方法後亦將率先運用，除可降低電廠之營運成本外，對本公司技術能力之建立及聲譽之提升亦有助益。

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四、心得與感想

1.根據美國經驗，1994 年以前業者對 PEMS 系統並不大感興趣，因為其預測準度較差，近年來，由於統計迴歸技術的突破，並結合人工智慧類神經網路及資訊、通訊等科技，使得 PEMS 模式預測準確性大大提高，截至目前為止，已有許多的排放設備建置 PEMS，且均已獲得美國環保主管機關的認證，故 PEMS 實用遠景可期。

2.就目前國內外運轉經驗，CEMS 耗費甚為龐大，就初設成本而言，機組建置 PEMS 祇需 CEMS 一半費用左右，另每年操作維護成本方面，PEMS 亦可較 CEMS 節省好幾萬美金，採用 PEMS 系統可節省大量的監測費用，降低電廠營運成本。

3.本公司自民國 88 年起即已開始進行 PEMS 之建置技術研發計畫，並以南部及興達電廠複循環機組作研究測試，俾建立 PEMS 模式，累積實測數據與經驗。目前我國 PEMS 尚無明確適用之法規，雖然各種標準方法及管理規範原應由環保主管機關研擬公佈，嗣由業者遵循；惟此一 PEMS 技術具有節省人力及經費特性，在實際應用上，本公司南部電廠及興達電廠分別有四

部及五部德製西門子同型燃氣複循環機組，通霄電廠有六部燃氣複循環機組，未來大潭電廠亦可能有六至十二部同一型號之燃氣複循環機組，若能經過立法以 PEMS 取代 CEMS，則可為公司省下大筆可觀的監測設施設置成本及運維成本，因此本公司當不待環保主管機關頒布 PEMS 相關規定，期以能持續進行技術研發，參酌國內外經驗，逐步建立 PEMS 標準監測、品保品管及驗證程序，並將成果提供環保主管機關作為制定法規參考，促其儘速修法頒布實施。

陸、出國期間所遭遇之困難與特殊事項：無

柒、對本公司之具體建議：

1. PEMS 標準監測必先由行政院環保署提出修法經立法通過後，本公司才有依據可遵循，而目前本公司的研究成果可提供行政院環保署作為參考。

2. 本公司當在環保主管機關頒布 PEMS 相關規定前，持續進行技術研發，參酌國內外經驗，逐步建立 PEMS 標準監測、品保品管及驗證程序。

3. 長期以來的 PEMS 相關技術經驗與傳承應加以保留，可置於公司綜合研究所所發展的知識平台上。

4. 現今以資訊公開及避免環保抗爭的角度來看，台電公司推動煙氣排放監測模式相關技術及營運管理體系內涵

應上網頁，使大眾能多瞭解本公司的作為，並樹立及提升公司之環保形象。

5. **有關國外長期以來對煙氣排放監測模式相關技術及營運管理體系之探討及研究資訊已相當多，應可經網路加以蒐集整理供為規劃參考，俾減少未來開發時不利之質疑及衝擊。**

6. **爭取環保主管機關認可，逐漸將 PEMS 技術推廣至其他氣渦輪機組。**

7. **與世界先進國家同步推動，建立台電公司之技術能力，提昇專業聲譽及民營化後之競爭能力。**

8. **可將此一技術提供其他民營發電業者(IPP)，或其他事業機構運用，獲取研發收益。**

捌、附錄

Summary: TEOM® Series 7000 Source Particulate Monitor

Quality • Service • Innovation
ISO 9001
Certified

Introduction

Particulate matter emissions from stationary sources is typically measured in the U.S. using USEPA Methods 5 or 17 or in Europe, using similar methods such as ISO 9096 or 13284-1, BS3405 and BS 6069 (UK), AFNOR/NFX 44052 (France), VDI 2066 (Germany), and UNICHIM Method N.422 (Italy) . The methods are labor intensive, slow and subject to uncertainty from filter handling, transport, conditioning and weighing. Using our patented TEOM® technology, R&P has developed a new source particulate monitor that provides *high resolution, direct mass measurement in real-time*. The Series 7000 monitor uses the same filter media as EPA and European reference methods to collect and measure stack PM mass concentration. However, this new method has been developed so that the entire measurement process including sample preparation, collection and quality control/quality assurance can be performed at the sampling location, eliminating the need for pre-sample preparation and post-sample processing.

The system can operate in three different operating modes; *traverse*, *continuous* (single point short duration), and *time proportioned* (intermittent) permitting mass determinations for compliance, diagnosing and optimizing emission control systems, and calibration of indirect measuring continuous particulate emissions monitors. The Series 7000 unit includes integrated source gas flow rate, temperature and molecular weight measurements allowing for automatic sampling at 100% isokinetic conditions. The on-board data acquisition and reporting system allows viewing of total mass collected and mass concentration in real-time. Integrated communications and reporting software also allows real-time or historical display of continuous data to be displayed in numerical or graphical format on a laptop computer.

Principle of Operation

The Series 7000 monitor collects a particulate matter sample using a filter while automatically maintaining isokinetic sampling conditions. The filter is affixed to one end of the mass transducer thereby allowing the collected particles to be weighed continuously resulting in a measurement of the real-time particle mass concentration. The instrument can also be configured with a cyclone to measure PM-10 or PM-2.5.

The TEOM mass transducer uses a short, straight inlet nozzle tube to isokinetically sample the flue gas and transport it to the filter. The mass transducer is a hollow tube, clamped on one end and free to vibrate at the other. An exchangeable filter cartridge is placed over the tip of the free end. This "tapered element" vibrates precisely at its natural resonant frequency. An electronic control circuit senses the vibration and through positive feedback adds sufficient energy to maintain a constant amplitude. A precise electronic counter measures the frequency, which has a direct relationship with mass. The relationship, expressed below, between mass and frequency can be derived from the simple harmonic oscillator equation.

$$f^2 = K_0 / m \qquad (1)$$

where f = frequency of oscillation
K_0 = calibration constant
m = mass

The calibration of the tapered element can be established as follows. A known mass, m, is determined gravimetrically and placed on the filter. K_0 can be determined by measuring frequency f_1 and f_2 where f_1 is the frequency measured without mass m, and f_2 is the frequency measured with mass m is loaded onto the filter. Using the relationship described by equation 1, for each frequency measurement:

$$f_1^2 = K_0 / m_1$$

and

$$f_2^2 = K_0 / m_2$$

From these two equations, K_0 can be calculated for the particular tapered element:

$$K_0 = (m_2 - m_1) / (1/f_2^2 - 1/f_1^2)$$

Importantly, the tapered element system is constructed using non-fatiguing inert material. Since K_0 is a function of the (non-changing) physical characteristics of the tapered element system, the tapered element retains its calibration indefinitely.

Once K_0 has been determined for a particular tapered element, it can be used for mass measurements. If the element is oscillating at the frequency of f_a and has a frequency response of f_b after an unknown mass is collected on the filter ($\Delta m'$), $\Delta m'$ can be obtained as a function of f_a, f_b and K_0 using the following equation:

$$\Delta m' = K_0 (1/f_b^2 - 1/f_a^2)$$

The starting frequency f_a can be defined at any arbitrary time, consequently the mass measurement does not depend on the knowledge of the previous filter loading. Tracking frequency with time yields the mass rate, and when combined with the sample flow rate through the filter allows calculation of the mass concentration.

During normal operation, the mass transducer is maintained at the stack temperature, a few degrees above the stack temperature, or at a constant elevated temperature to provide the desired thermodynamic sampling and measurement conditions.

Modes of Operation

The Series 7000 Source Particulate Monitor can be operated in three sampling modes. All three modes can use isokinetic or fixed sample flow:

- *Continuous* (short duration) PM concentration measurements at a single sampling location.
- *Traverse* measurements of stack PM concentration at two or more sample points across a stack cross-section axis.
- *Time Proportioned* (long term, intermittent) sampling of source PM concentration at a single sampling location.

  NOTE: All of the above sampling modes can be operated with sample stream dilution ratios of up to 2:1 (2 parts dilution air to one part sample stream), and higher in some cases.

The *Continuous* sampling mode is used to perform short duration tests, typically for between a few and 24 hours, at a single sample point location. Filter life is a function of the type of PM as well as the concentration being measured. Consequently the duration of sampling between filter changes varies widely from one emission source to another. As a guideline, the maximum acceptable filter loading is 8 - 10 mg, at a flow rate of 1 - 2 l/min. Therefore, at low concentrations, say 5 mg/m^3, filter lifetime would be approximately 16 to 32 hours. At higher concentrations, say 50 mg/m^3, filter lifetime is likely to be 1.5 to 3 hours without dilution.

The *Traverse* sampling mode allows the instrument to characterize actual emissions from the stationary source more accurately by taking samples from several discrete sample points in the process or stack in a manner similar to US EPA Method 5i or Method 17. Typical operation of the Series 7000 monitor in this mode is as follows.

The operator configures the instrument to provide a two minute average concentration in the traverse mode. The operator then can insert the probe into the gas stream and position the mass transducer at the first sampling location. Through the hand-held terminal, the instrument is instructed by the operator to enter the initial filter desiccation/stabilization period. During this period the instrument is in the purge mode causing dry, clean air to flow through the filter, thereby conditioning the filter to a dry, stable initial filter mass. After the filter mass stabilizes, the filter mass reading is tared to zero and sampling is initiated. After at least two minutes of sampling elapses, the instrument is placed in the pause mode, the operator moves the mass transducer to the next sample point, and sample measurement is turned back on. Sampling at each traverse point continues in this manner until all desired sampling points have been tested. Once the traverse is completed, the operator instructs the instrument to switch into purge mode causing the filter to undergo the final desiccation process which dries the filter and any collected particulate matter. The operator then withdraws the sample probe from the stack. Once outside the stack, the mass transducer is outfitted with its insulating jacket and the instrument is prepared for capturing any particulate that may have been retained in the inlet during sampling. Once the total mass reading has again stabilized, the inlet "brushdown" procedure is used to remove any particulate matter onto the filter.

The average mass concentration for all sample points is then calculated automatically by the instrument from the combined total mass of particulate matter captured at each sample point plus any mass collected during "brushdown," divided by the total sample volume processed. The results for each sample point and for the average of all sample points are displayed on the hand-held terminal, and are stored for report generation using the PC-based RP7000 software provided with the instrument.

The *Time Proportioned* sampling mode consists of a (user-defined) short duration sampling period followed by a longer period without sample collection. This is accomplished by using the purge feature of the instrument to prevent stack gas from being extracted through the sample filter during periods between samples.

Prior to initiating the first sample collection period, the user defines the sample period, the purge period and the time at which the first sample is to be initiated. The mass transducer is then positioned at the sample point and sampling is initiated per the sampling program. Sampling continues until the user-defined time period elapses, and then the instrument automatically switches into the purge mode. The purge mode continues for a user defined time period and then the instrument automatically switches back to the sample mode. This process can be repeated until maximum filter loading occurs or a preset time period is attained.

A *sample dilution* feature is available for each of the above sampling modes, allowing the instrument to maintain continuous or intermittent sampling for longer periods between filter changes. Since the purge flow is only needed during the purge mode, it can be made available during sampling to dilute the incoming sample gas stream. Both the purge flow rate and sample flow rate are controlled using high-precision flow controllers. The purge flow can be precisely metered into the sample inlet during sampling even while maintaining isokinetic sampling conditions.

System Specifications

The complete system consists of the mass transducer, probe with or without probe extension, boom support, probe bearing assembly, pneumatic and electrical umbilicals, control unit, and pump/power unit. The system is designed to be portable and permit sampling in stack locations up to 23.3 feet (7 m) in diameter for USEPA-type testing, and up to 20.7 feet (6.2 m) in diameter for the ISO 9096 test procedure. The modular design facilitates serviceability while providing portability, enabling installation in a wide variety of sample port and sampling platform configurations and allowing for interfacing to other sampling equipment.

The instrument is able to operate in ambient temperature conditions ranging from -20 to +50 °C and under source conditions where the relative humidity is up to 100% as long as there are no undivided water droplets and the sample gas temperatures does not exceed 200 °C. Interchangeable sampling nozzles are provided to allow for sampling in gas velocities up to 90 feet/sec (27 m/sec).

The system is configured with four (4) analog inputs and four (4) analog outputs. Each input and output can be configured for 0-1, 0-5, 0-10 VDC or 4-20 mA signals.

An optional QA Test Kit contains the necessary calibration and verification standards, test equipment and supplies to perform all QA/QC activities at the test site, thereby enabling the user to produce a validated emission test result on-site at the conclusion of the test.

User Interface

Operation and calibration of the Series 7000 monitor is performed using a dedicated, hand-held data terminal connected to the Control Unit through a standard RS232 umbilical cable. The instrument is operated using menu options displayed on the hand-held terminal display to access each operating mode or to access instrument calibration and/or maintenance routines. The menus prompt the user to select the desired operating mode and then lead the user through the appropriate steps for each part of the test procedure. The result is a test performed in a standard, reproducible sequence. When the user has completed the final menu instructions, the test is complete and the user can proceed with the generation of results in Microsoft® Word and Excel format based upon data stored in the monitor.

At any time during a test, data displays on the hand-held terminal can be accessed that report current mass concentration, total mass collected and instrument operating status messages. Also, various instrument operating parameters such sample flow rate, temperatures of the mass transducer, inlet and sample umbilical, stack gas velocity and stack gas temperature can be viewed on the hand-held terminal during the test.

An integrated RS232 serial port in the Control Unit permits connection to a laptop computer. R&P has developed laptop-based communications and data management software named RP7000 to connect with and control the instrument operating software. The RP7000 software has the following capabilities:

- Real-time display of current instrument parameters and test results.
- Downloading test data.
- Uploading operating configuration information such as test location name, ID, stack dimensions, etc.
- Generation of pre-defined and user-configurable reports.

Results

Examples of data captured using each operating mode are shown below. The first two examples present data to illustrate typical patterns observed in viewing real-time data during a test. The next four examples present data collected using the different instrument operating modes. The final two examples describe precision and accuracy information for this new method. The last example also presents data collected using the dilution feature while in the continuous sample mode.

Example 1 - Short Duration Continuous Test Mode

Figure 1 presents a short duration continuous test at a coal fired power boiler. The figure has been annotated to note typical patterns observed in real-time. Immediately prior to the start of sampling, the filter is purged with dry air for several minutes to desiccate the filter to a constant weight. As sampling commences (time = 14:58), particles and moisture begin collecting on the filter. Through the first few minutes of sampling, the filter equilibrates to the sample gas moisture condition. The uptake of water by the filter for the first several minutes of sampling, labeled "Water Uptake Transient," results in a short-term over-reporting of mass concentration by the real-time data. Any moisture absorbed during sampling is removed after sampling has been completed through a post-sampling, filter desiccation step. This is noted on the chart as the "Water Loss Transient." Since the filter is desiccated until a stable mass reading is obtained, the moisture absorbed during the sampling process is eliminated from the total mass collected, and the final result is attributable only to the particulate matter captured during the test.

Example 2 - Inlet Brushdown Results

Figure 2 is a graphical representation of the instrument response when recovering particulate matter from the sample inlet after completion of the final sample desiccation. The total mass of recovered particulate matter during the inlet recovery process ("Inlet Brushdown") is combined with the mass (dry) determined during sampling to calculate the total mass (dry) gain for a test. The total mass (dry) is then used with the sample volume measurement (dry) to calculate the average mass concentration over the total test period.

Example 3 - Continuous Test Mode

The next example (Figure 3) presents results from the exhaust gas flow of a baghouse air pollution control system at a copper smelter. Data were collected approximately every three seconds, averaged, saved and reported every two minutes, allowing representative measurement of quick changes in PM concentration. Cycling of data between high and low PM mass concentration levels results from the 6-bank bag house going through its 36 minute cleaning cycle. This cycle consists of a sequence in which one bank of bags is closed for 6 minutes for backflushing. It is then opened and the next bank is closed and cleaned, and so on. One of the banks had a bad seal in its shutoff door, and every time it was closed a stream of fresh air (as evidenced by a 6 °C decrease in the flue temperature) is allowed to mix with flue gas. This resulted in a reduction of the PM mass concentration for the 6-minute cleaning of that bank.

Other variations in PM concentration may be explained by the differences in the efficiencies of each bank of bags. For example, a bank may have a torn bag, allowing excess particulate mass to pass into the flue gas, or the opening of a door may re-entrain particulate matter from surfaces. This data set shows how useful the instrument can be for studying control device parameters, either separately or in conjunction with a compliance test.

Example 4 - Comparison of Series 7000 Data to Opacity Monitor Data

The next example illustrates the use of the Series 7000 monitor's Continuous Mode to correlate real-time direct mass measurement of particulate matter to measurements taken using indirect emission monitoring methods such as opacity, light scattering, beta attenuation, etc.

First, a traverse is completed to determine the optimal location to obtain a representative sample. The sample probe is then fixed in that location and the Series 7000 monitor is configured to operate in its Continuous Mode. Figure 4 shows the relationship between mass emissions measured by the Series 7000 monitor and opacity measurements of the precipitator exhaust on a cement kiln. The periodic dual peak excursions are attributed to the cycling of the rappers nearest to the precipitator outlet.

Example 5 - Traverse Mode

Figure 5 contains an example of traverse measurement data. This test was performed at a coal fired power boiler that supplements its fuel with wood waste. The probe was positioned at six equally spaced locations within the stack. Sampling was initiated at the position 102 inches (2.6 m) from the sample port and continued for 10 minutes, then moved stepwise until sampling was completed at 42 inches (1.05 m). Measured PM across the traverse was very consistent with values generally between 25 and 50 mg/m^3, indicating a well-mixed gas stream with little stratification across the duct.

Example 6 - Time Proportioned Sample Mode

Figure 6 shows data collected using the Series 7000 monitor operating in the time-proportioned, or intermittent, sampling mode. This data set is from the same facility described in the Figure 5. In this example, a 30-second sample was taken every ten minutes. The measurements show PM concentration ranging from a low of 30 mg/m^3 to a high of over 300 mg/m^3. The high PM concentration spikes were periodic and correspond to rapping in the precipitator. Increased filter life in sources with high PM concentration is the main benefit of this operating mode. A typical use of the intermittent sampling mode is to provide a mass-based calibration of a continuous stack PM monitor that uses a surrogate measurement technique.

Example 7 - Method Precision

Method precision can be determined by performing simultaneous measurements with two identically prepared instruments sampling in very close proximity to each other. The test data presented in Figure 7 were collected in the exhaust duct following the electrostatic precipitator at a large coal-fired power boiler. Instrument 1 (labeled Prototype 7) and Instrument 2 (labeled Prototype 3) were installed in adjacent sample ports in the exhaust duct. Throughout sampling, the sample inlets of the TEOM mass transducers were separated by a distance of approximately 8 to 10 inches (20 to 25 cm). Both instruments were programmed using the same instrument operating parameters and allowed to sample for approximately 8 hours. The percent difference in total mass determined by each instrument was 2.5%.

Example 8 - Comparison to Manual Methods

The final example, Figure 8, presents particulate matter monitoring data from testing at a coal-fired utility boiler. Simultaneous testing was conducted using the using the Series 7000 monitor and an integrated in-stack manual method. The system was configured to sample unattended overnight for a period of about 14 hours. The measurement was made using the continuous mode with a sample dilution of 50% stack gas to 50% dilution air (v/v). The results show that the difference in mass concentration between the Series 7000 continuous method and the manual measurement over the fourteen (14) hour sample period was +1.5%. Please note that this test was performed using dilution *at an average mass concentration of only 1.7 mg/m³*.

Figure 1. Continuous Operation of Series 7000 Monitor

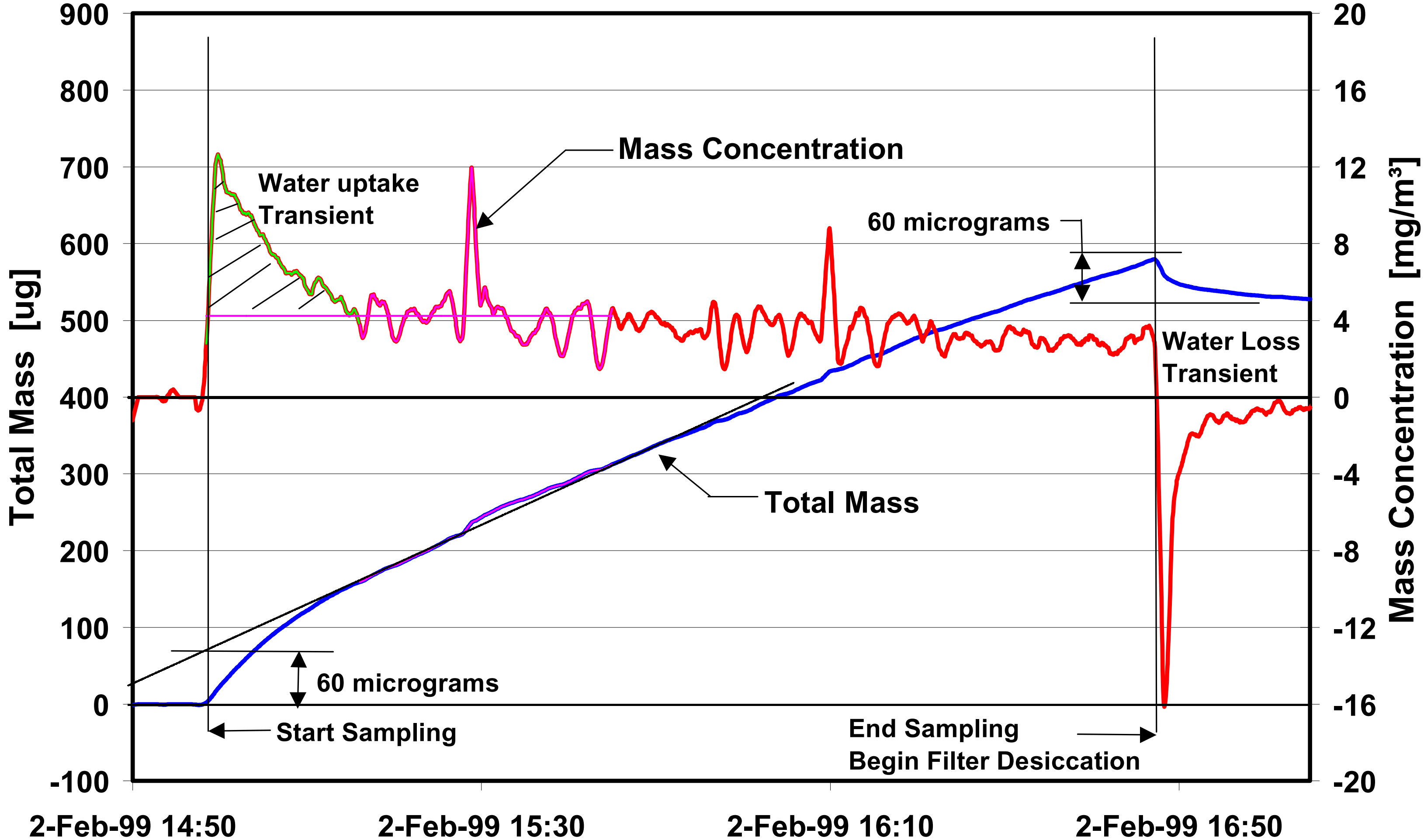
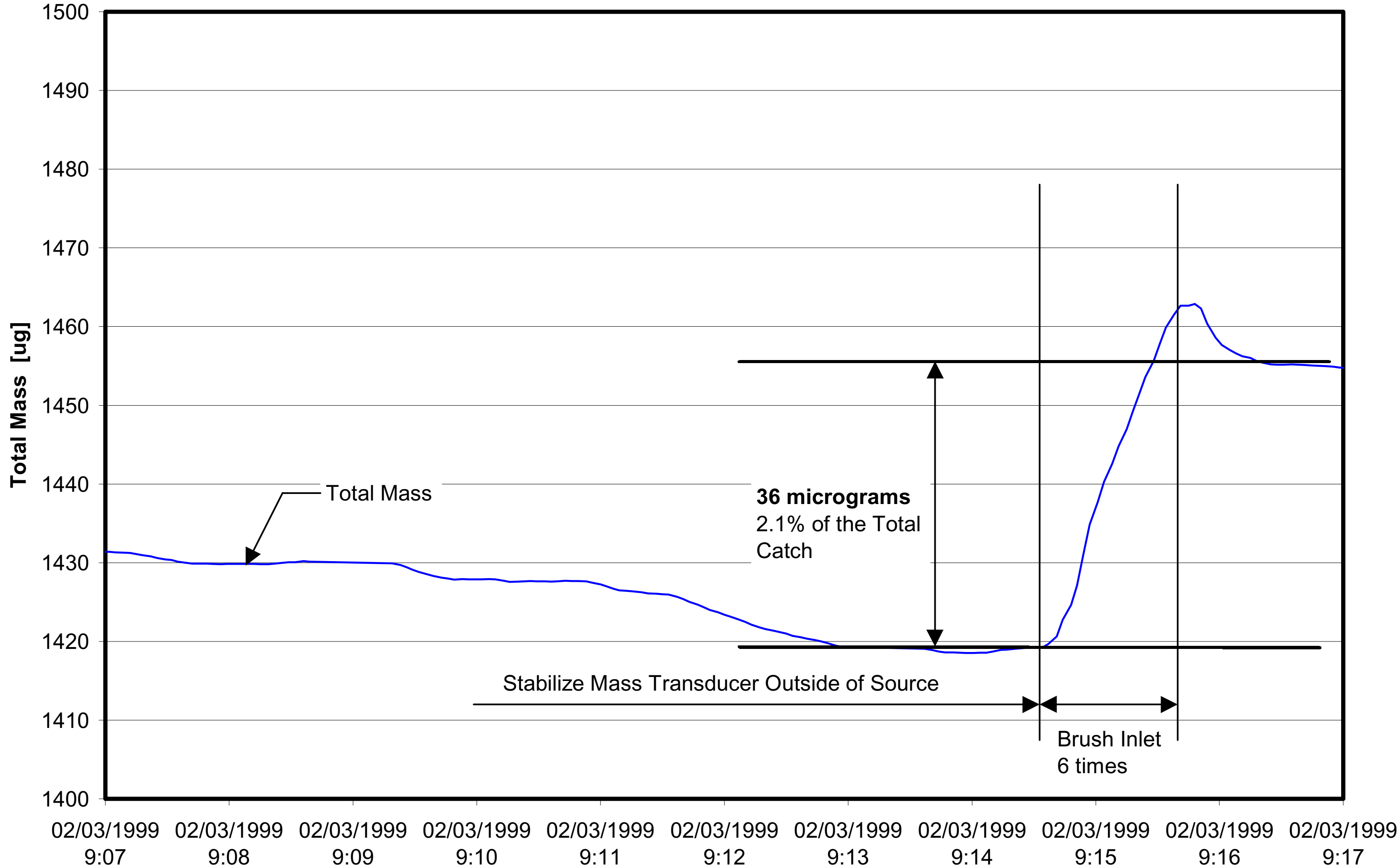


Figure 2. Inlet Brushdown



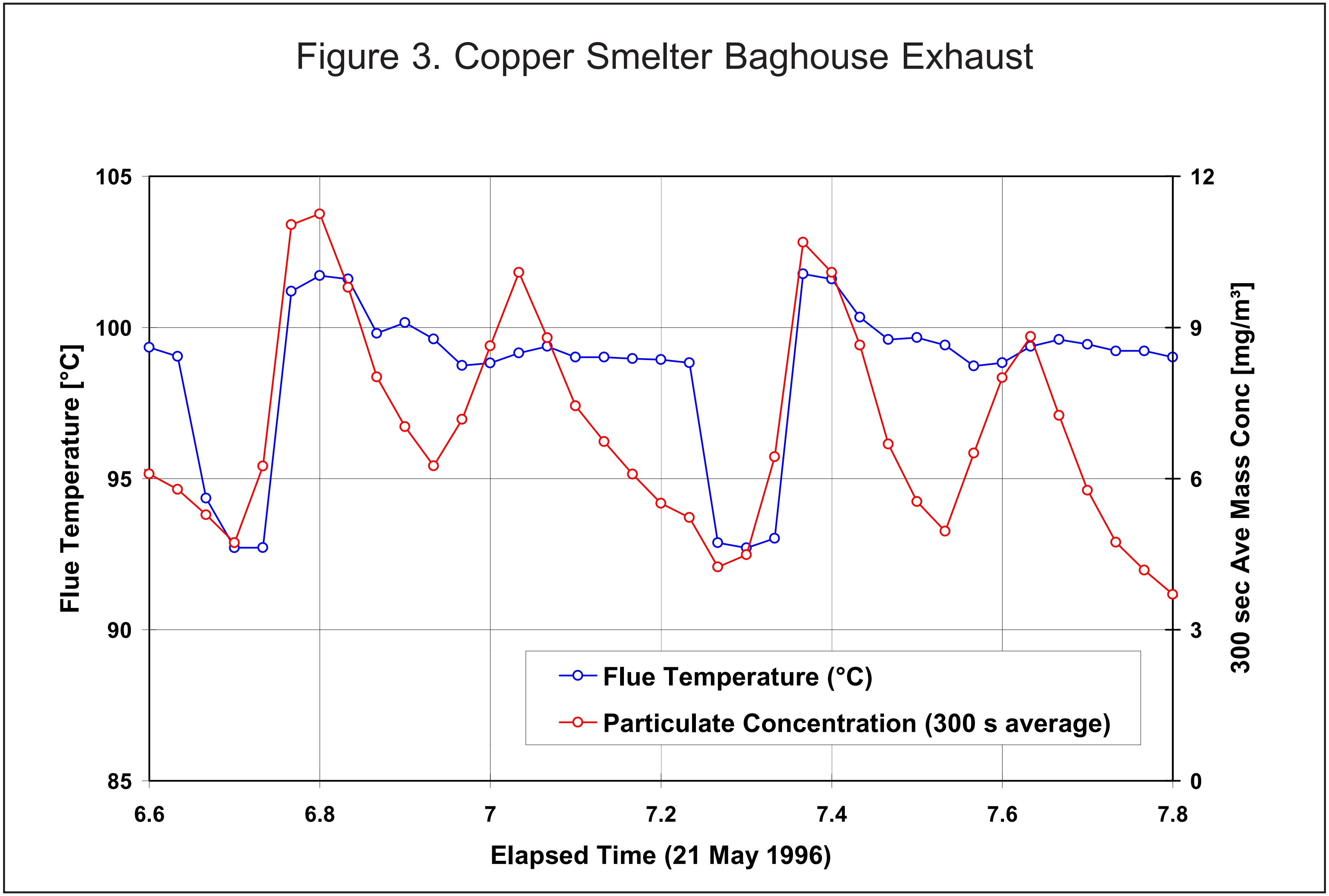


Figure 3. Copper Smelter Baghouse Exhaust
105
100
95
90
85
12
9
6
3
0
6.6
6.8
7
7.2
7.4
7.6
7.8
Flue Temperature [°C]
300 sec Ave Mass Conc [mg/m³]
Elapsed Time (21 May 1996)
Flue Temperature (°C)
Particulate Concentration (300 s average)

Figure 4. Mass Concentration Vs. Opacity at a Cement Plant

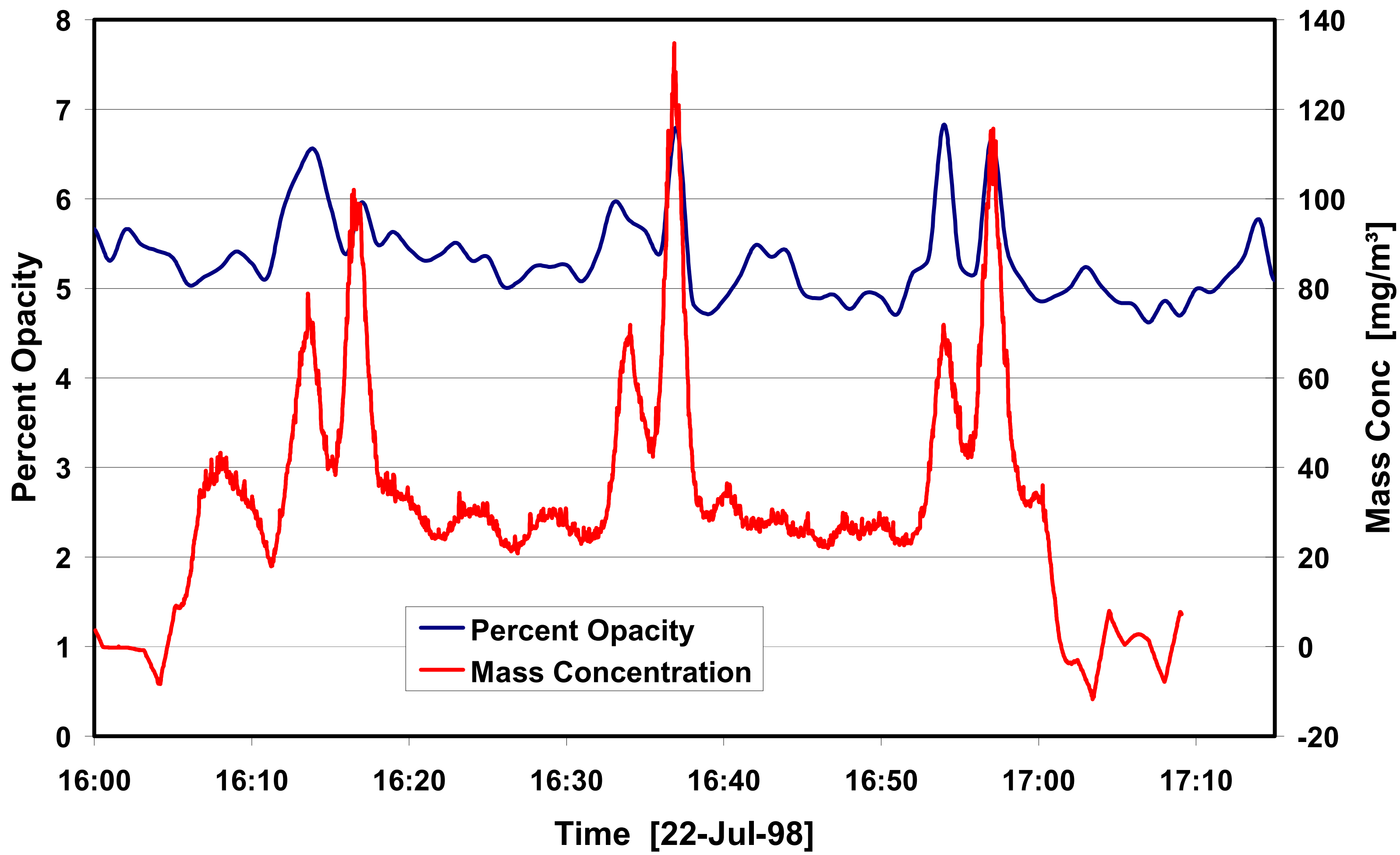


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Figure 5. Series 7000 Monitor in Traverse Mode

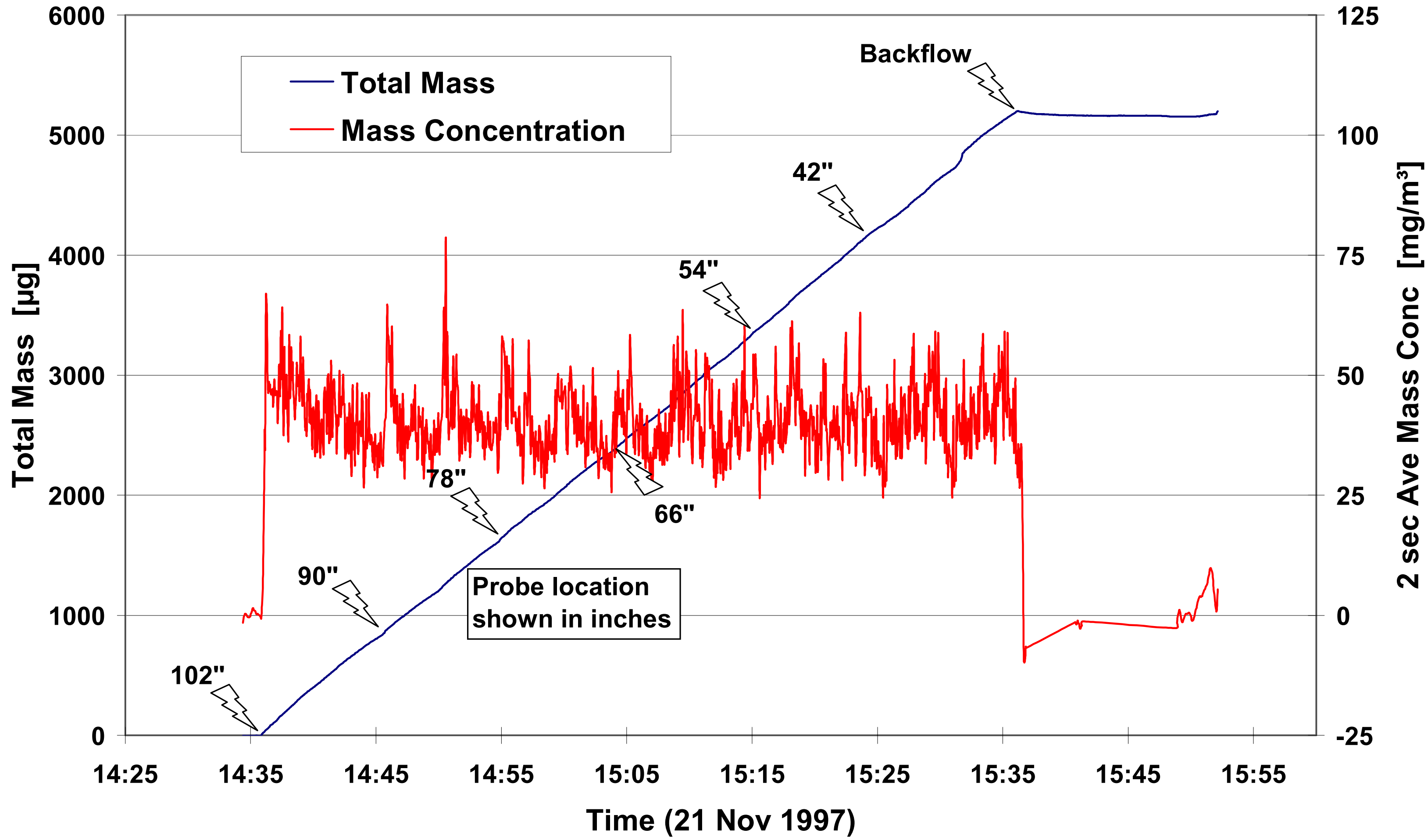

Figure 6. Series 7000 Monitor in Time Proportioned Mode

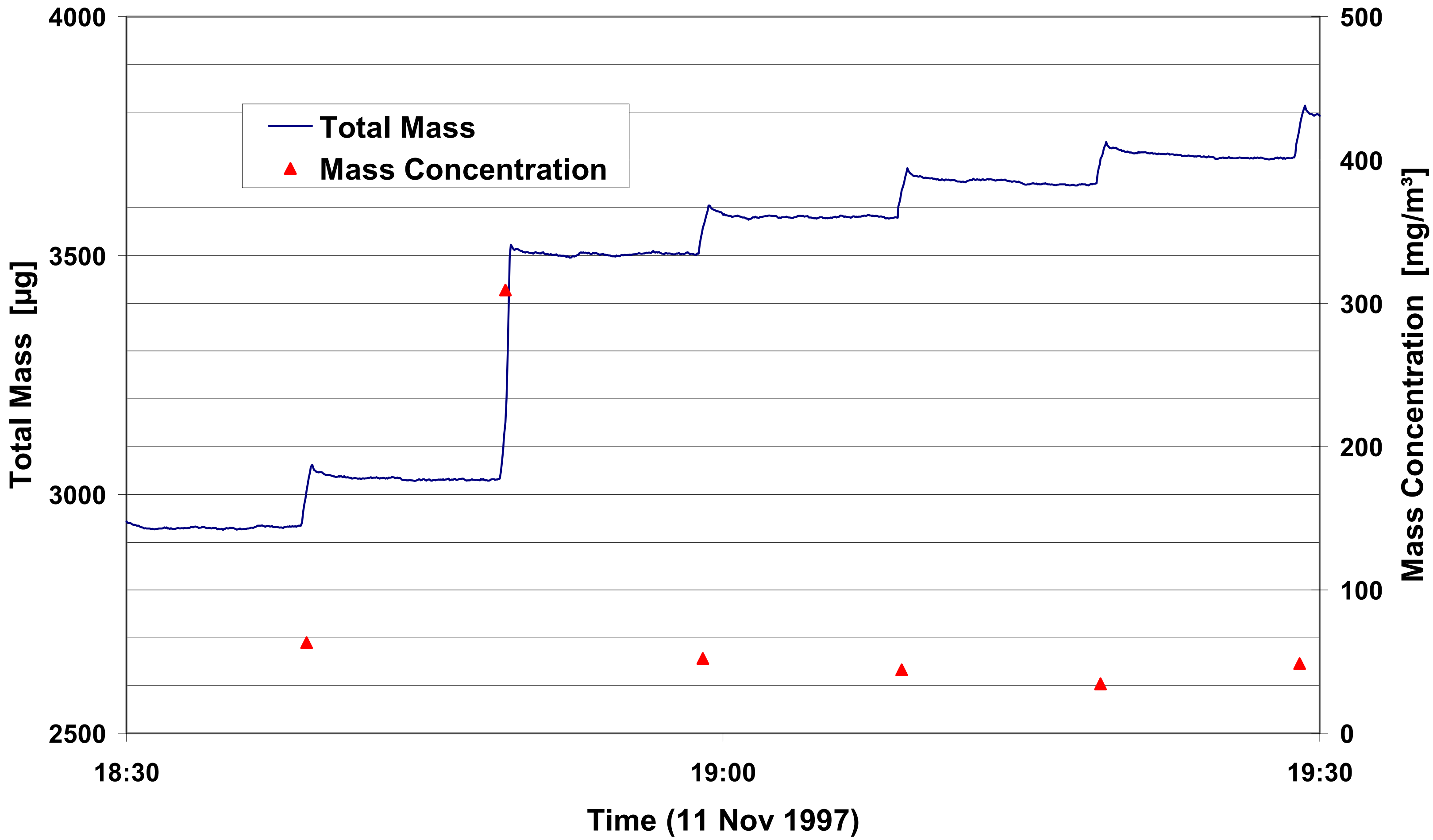

Figure 7. Series 7000 Precision Results

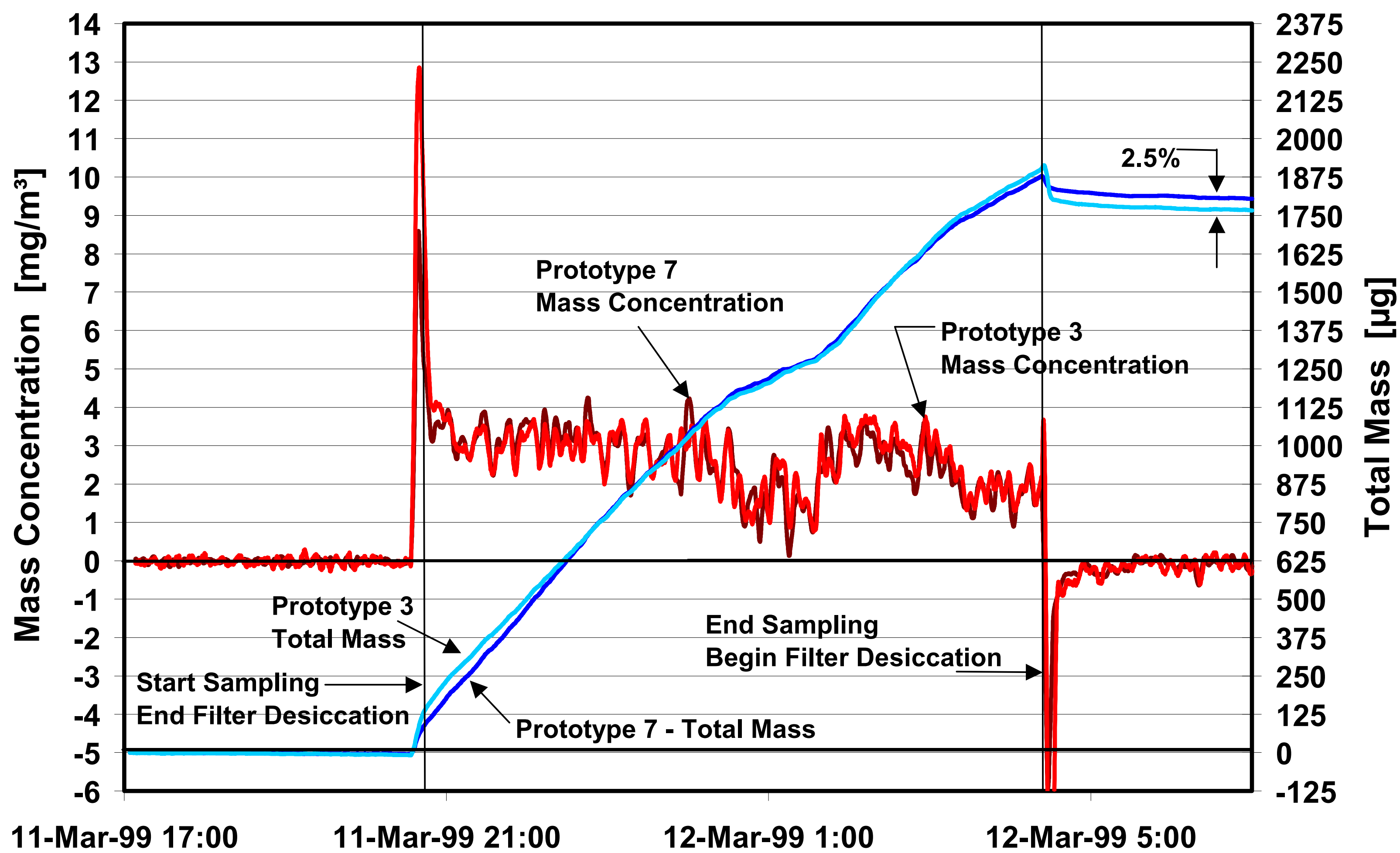

Figure 8. Low Contration Emission Test Using Dilution
with Comparison to Manual In-Stack Method