Aerosol Characterization of Wood-Fed Brick Kiln Effluents In Ciudad Juarez, Chih., Mexico

A SCERP project Progress Report "Measurements of Air Quality in Juarez,Chih.,Mexico

C.W. Bruce, July 1999

Abstract

Basic operating properties and effluents of brick kilns typical of this region have been characterized in a study of somewhat more than one year. The key measurements were of aerosol densities, buoyancies with wind driven vertical air flow and specific temperatures. Electron microscopy together with X-ray spectroscopy of individual particles add detailed information on composition and size. Time histories of effluent flow for differing styles of operation provide valuable information with regard to effects on efficiency. Data for several kilns are contrasted with those for a kiln specially modified according to a design by Robert Marquez of NMSU for reduced emissions as well as the effects of variations on that theme. The comparisons are conclusive; effluent emission rates are reduced to a small percentage. Other advantages to the owners of modified kilns such as significantly reduced operating cycles and decreased feed rates without penalty become apparent from the measurements.

Following this summary a more detailed report of the measurements of each burn is appended for details and assorted information.

Summary

Unmodified Kilns:

Reversing the logical and starting with the primary end product, the dry particle flux per unit cross-sectional area is of most interest for the brick kilns operating throughout the city. The average peak for the flux areal density for burns in their final hours is found to be 47 g/minute/M^2 with a probable variation of 37%. This is on the basis of the four burns conducted on three different kilns. Construction varies little in essential respects with total cross sectional areas ranging from about 5 to 16 M^2 so that the total peak flux can me seen to be between about 1/4 to 3/4 kilogram per minute. Values of more than one kilogram per minute were measured during this series.

Both feeding and stoking affect the production of smoke and more than forty feed cycles were analysed for statistical features. The purpose is to obtain a better idea of the relationship between peak smoke density and its average. Some fuels produce virtually no stable period of smoke before decay, especially for times later in the burn cycle (more mature). Very thin pieces such as woodshop scraps tend to do this. Figure 16 is an example of this. Thicker wood, for example from pallets, produce initial intervals of relatively steady smoke densities (average 2.2 minutes) followed by a roughly exponential decay almost to background levels. The statistical decay factor (e^-1) for the many thick-wood feeding cycles was 2.5 minutes. Usually the feeding cycles are repeated every 9 - 12 minutes. Stoking also produces increased smoke but less dramatically than for feeding.

Before discussing the use of aserrin or sawdust, which is generally much more continuously connection established, about the same for the two cases so the reduction in net flux is roughly the ratio of the areas. Since the flux changes with time, another counter-variable would be necessary to explain this phenomenon as a saturation effect.

In the first of two configurations used, only the underground filter and the two equal-area flues were employed. For this configuration, the fluxes in the filter output flue ranged from 13 g/min to 38 g/min. From the data of five burns the mean flux within three hours of termination of the cooking cycle was 24 g/min+- 51% probable variation. Figure 17 in the report indicates that the filter gives a reduction in the output flux throughout the cycle of approximately a factor of two.

A clever idea of R. Marquez was to have two kilns on opposite ends of the underground filter. The thermal flux from one would pass through the second for further filtering and drying effects. That load could then be cooked at lower cost without moving the bricks. On the second trial of this arrangement measurements were made that indicated that the second stage of filtering was roughly as efficient as the first. The peak net dry particulate flux was computed to be 6 g/min with an average in the vicinity of 2 g/min. Compare this with unmodified numbers of the order of hundreds of g/min. The design of the kiln enclosure and the filters are surely both subject to improvement. At this point, a whole catalogue of filters becomes practical that would have been unthinkable at the normal high fluxes.

The buoyancies in the two output flues are usually not very different. They are, as expected considerably higher than for the tops of the open kilns. Losses in the underground filter system might reasonably account for the losses (one can see dribbles of smoke from various pores). Combined data give a value of 1.64 M/s +-10% probable for the filter input flue and 1.29+-21% probable for the filter output flue. The average (mature) buoyancy atop the second filter (kiln) is found to be 0.36 M/s, although, for one of the two burns, the value was higher. It is probable that the West wind contributed to this value of about 0.8 M/s.

Temperatures for the modified kilns also increased fairly linearly with time. Never did they approach the 600 degrees C that indicated cycle termination although the temperature difference between the upper region of the kiln interior and that in the filter input flue is only a few degrees. At the capping of the filter input flue (usually about 1.5 - 2 hours after initiation of the burn), a change in the rate of temperature increase was seen as seen in figure 23.

Several observations in the course of this study appear revevant to kiln operation. The first of these relates to the moisture content in the filter output flue. Filter measurements in this flue were made using a relatively massive filter holder but its temperature was not held constant. As was noted in the report as early as the January 1999 burn, water condensed on the filters. The author decided to see how moisture content related to the burn cycle and dual sets of measurements were performed in the two flues of the modified kiln throughout the burn cycle. The result was that, although only qualitative, the density of water in the effluent plume clearly increased during the cycle until until about 3 hours before the cycle ended as can be seen in figure 18 (cycle duration was about 9 hours). Following the rise, the availability of water in the system steadily decreased until it reached a value depending on the combustion material, the only process that continued unchanged. Thus the suggestion is that the moisture came from the bricks themselves.

Within the body of the report an anecdote is told concerning the operation of the modified kiln. It was an amusing incident but it showed that operational procedures could be changed to optimize economy of fuel. The presentation is found in the June 3rd report and the related illustration is found in figures 27 and 28. Basically, the kiln was throttled for hours withou affecting the progress upward of the temperatures in the upper regions of the kiln. When the feeding process was uninhibited by visitors, the temperature rise rate did not change.

Finally, it was seen that the burn cycles were greatly reduced from more like 15 hours to about 8-9 hours and, further, the total amount of fuel was reduced. The flux of health endangering particles integrated over time thus is reduced by another factor, not precisely the ratio of cycle durations but directly related to that.

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Introduction

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Although measurements and analyses of brick kiln effluents continue to be made, (for example only wood-based fuels have been used in this study) a clear idea of particulate and gaseous aerosol concentrations have emerged along with dependencies on various facets of kiln operation. The great degree of current interest and even urgency in this issue dictates that these results not be delayed.

. Another reason for reporting at this stage is that too much information heard in the community is based on sheer ether and perhaps this progress report will help to bring the subject back to earth. Hopefully it will aid in understanding existing ladrillera operations as well as the status and benefits of the modifications.

Preamble to the Measurements

The types of information sought in this study can be categorized as follows. Most important is the mass flow of the particulate aerosols for each kiln configuration (does kiln shape make a significant difference?) as functions of time throughout the baking cycle and for typical (and atypical) patterns off feeding and stoking. The morphology and composition of the emitted aerosols and the concentrations of toxic gases must be determined for the alternative fuels. Specific temperatures and temperature time profiles can reveal information about the cooking process.

The modified kiln has produced dramatic reductions in the fluxes and total mass emitted and, with operational variations, is heavily represented in the present findings. The types of instrumentation used for the measurements of this report are loosely based on previous soot plume characterization and modeling research (reference 1) and, are presented in appendix I.

At this point it seems best to report on the measurements in the order in which they were made because that process was one of learning which resulted in almost continuous modifications. Results of the particle microscopy and a synopsis of the measurement results follow.

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Measurements in Historical Order

A. Kiln of Sr. Juan Jimenez, March17, 1998

Measurement summary: Sensor probes mounted on a rail with modified RAS atop kiln for continuous double aerosol sampling. Modified MRI used with long probe...in part to compare sampling from tube with very direct probe.

Data: Aerosol density time histories, temperatures using Cole-Parmer system, 3 gas samples, 9 type AE filters.

Fuel: Mostly pallets, some triply

The inside diameter of this kiln is 2.8 M. It is well banked into the standing clay, extending about 2.2 M above the ground level on three sides and fed on the south side which is about 10 feet below the other sides. The top of the bed of bricks to be cooked was about 0.4 M below the rim. For this burn, a retractable probe system on rails (see figure 2) was placed across the top of

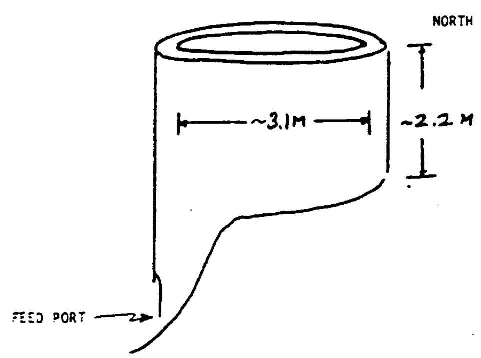


Figure 1. Sketch of kiln.

the kiln. A small nephelometer (modRAS) was mounted at the probe end of the carriage. The set of probes was located about 20 cm below the rim of bricks and about the same distance from the top surface of the bricks to be cooked. Aspiration for this nephelometer and electrical cables passed through a larger tube which was used to feed a much larger nephelometer system (modMRI) which was mounted more remotely.

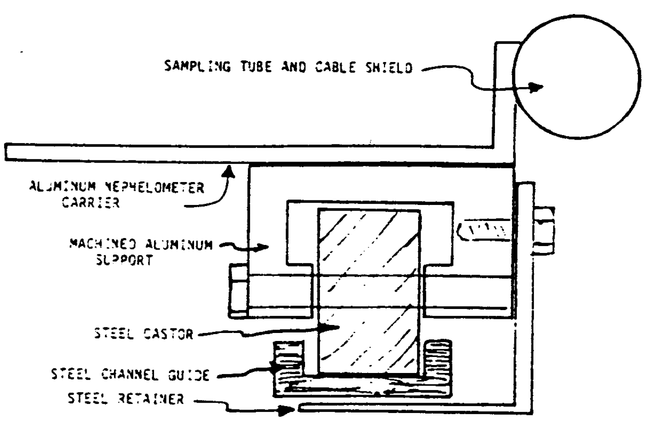


Figure 2. Cross section of carrier with track channel underneath. Used for sampling at first burn.

Gravimetric samples were made in proximity with the the colocated probe intakes. The gravimetry was used to calibrate the nephelometers (reference 2). The wind sensor was of an acoustic manometric type developed by the author (reference 3) but the high level of prevailing winds on this day (highs estimated at about 9 M/s) precluded accurate buoyancy measurements. The burn started at about 8AM and, by 9:15, the emitted smoke was still confined to a small sector approximately defined in the figure below.

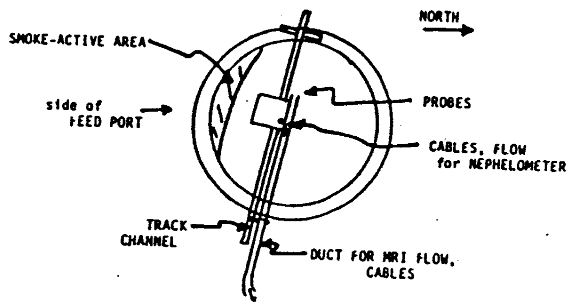


Figure 3. Smoke-active region early in the cooking cycle and location of sampling carriage. Smoke emission was fairly uniform over the surface by about 2 PM for a cycle which started at about 8 AM. The heating portion of the cycle was expected to terminate at about 10 PM. Workers progressively covered the kiln top with fairly closely spaced bricks, starting on the most smoke-active side (south), after about 11:30 AM but smoke emission did not appear to be inhibited.

Temperature measurements using the factory calibrated Cole Parmer probe were made at the level of (or one brick under) the top surface of the load. An idea of the development with time is shown in figure 4. The probe was reinserted within the center of the smoke active region for each measurement so apparent variations with time (actually space) are strong at and near the surface. Scouring by the wind and phase in the feeding and stoking cycles also influence the temperature values . Nevertheless the value rises faster (and farther) than for later measurements on other kilns and raises the question of what value it would have reached by the end of the cycle.

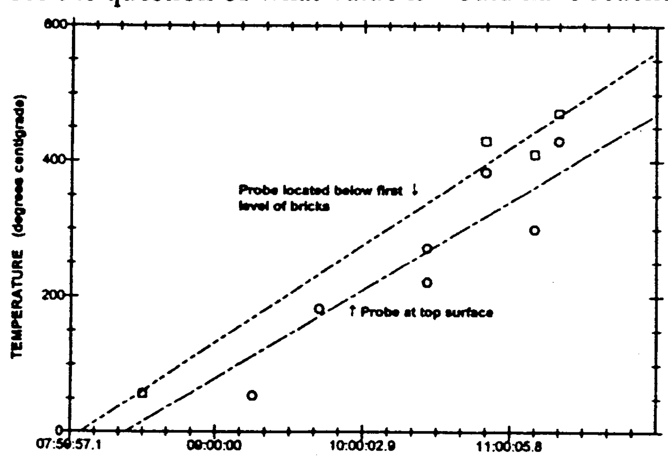


Figure 4. Time development of the temperature atop the kiln in the region most active in smoke emission.

Meanwhile, midday aerosol peak densities were in the vicinity of one gram per cubic meter. Examples are shown in figure 5. Since the probes were moved throughout the smoke region on this day feeding cycles may not in general be extracted from this data. This is because the carrier was used to place the probes in the thickest of the smoke (placement determined by the sometimes strong wind) to indicate the peak densities. The nephelometers were calibrated using the gravimetric data. The two minute filter samples produced a maximum average density of 396 mg/M^3. Most were below 100 mg/M^3. All were sampled at a velocity of approximately 1 M/s, an approximation to the expected buoyancy. As can be seen from the sample data, the two systems tracked fairly closely but with a 15-20 sec lag for the remote sensor (also a function of integrating time for that unit). The proportionality of gravimetric and optical results was within 9% probable error for the process of calibration. One purpose of the dual probe setup was to see if the remote probe would also be proportional to the density for the principally small particles produced by the kilns.

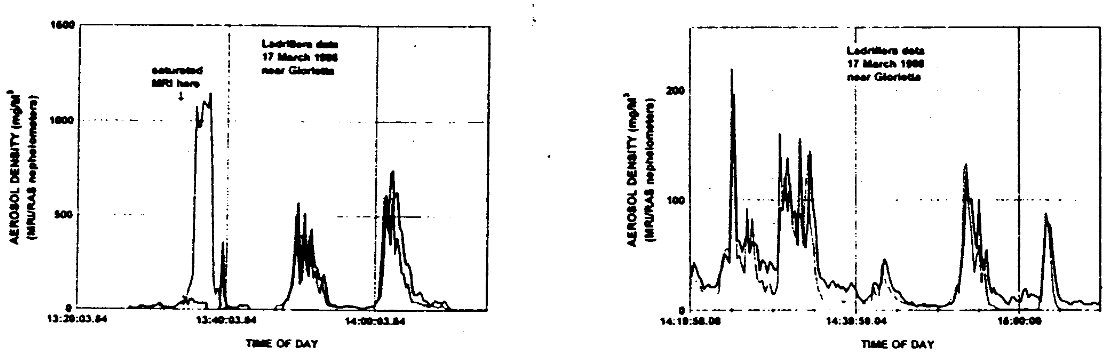


Figure 5. Sample time intervals of the aerosol density data by the two probes. Regions of high smoke density near the kiln surface (below the brick rim) were sought in variable (very low to about 9 M/s) winds. The smoke density drops to very low values between feeding cycles.

The aerosol mass flow may be estimated from the data accumulated. For example, at 12 noon on this day, approximately 40% of the top area of the kiln was active. At this time the average smoke densities in the thickest of the feeding cycles were between 600 and 800 mg/M^3. Then

$$dm/dt = (rho)(A)(Y)$$

where- (rho) is the aerosol density (g/M^3), (A) is the kiln-top active cross sectional area (M^2) and (Y) is the plume buoyancy (M/s).

This estimate gives a peak dry aerosol flux of about 100 g/min for noon time and about double this for two hours later.

The average net dry aerosol flux can be estimated (for this burn) using the following approximate numbers : (a) the average time between feeding cycles is about ten minutes and (b) the duration is about three minutes (to use peak densities). Therefore the average dry aerosol flux was about

30 g/min at noon and about 60 g/min at 2PM. It will be seen that, for some reason, Don Juan's unmodified kiln produced less smoke (and higher temperatures) than the other unmodified units of our measurements. A visual comparison with other plumes on that day agreed; the others produced thicker plumes. The fact that the owner of this kiln, Don Juan, a careful and thoughtful person himself, used a relatively clean fuel (pallets, relatively thick, uncoated wood) and fed the kiln carefully may be part of the reason. As we will see, the manner of feeding and stoking can make a significant difference in the output flux. And perhaps the others were using fuels that produce more smoke. They have been known to burn rubber, etc.

B. Modified kiln of Sr. Enrique Chavez, 15 Oct 1998

Measurement summary: Again two nephelometers, a new buoyancy measurement using a Young sensor with especially low stall velocity(but unfortunately wind also!). Filter and aerosol density measurements were made on both Kiln smoke filter input and output flues. Winds became very strong with air full of sand so terminated measurements at about 3PM.
Data: AE filters (8) throughout day, PC filters for SEM/EDAX analyses.
Fuel: Typical lena (pallets and other fairly thick wood).

These burns must of course be planned ahead of the actual date and usually are planned well ahead of it. The result is that low winds are not guaranteed although occasionally the date has been altered due to a long range forecast that forshadows winds. A measurement problem is that it's important to be able to determine baseline data on kiln parameters without cross winds. Cross winds can drive kiln circulation from both ends of the kiln, and thus alter burning rates in the kiln (depending to a degree on feed orientation).

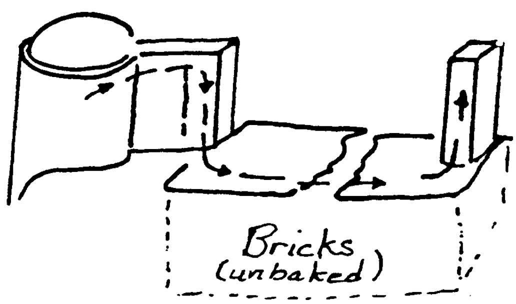


Figure 6. Sketch of modified kiln with flues and filter.

To put this in other words, flow in the presence of winds may not be simply buoyancy. Winds can alter flow by force feeding and by extraction at the kiln output surface by means of induced vacuum. The buoyancy is needed because that is a fundamental parameter of the kiln or thermal source with linear significance in the flux. For example, the modified kiln gives a quite different value. The net updraft can be measured accurately, even if the wind is strong and has been possible for the burns of this study. Nevertheless, since strong winds were predicted on this particular day, it was less than an ideal one for introduction of the new buoyancy sensor which is sketched in figure 7.

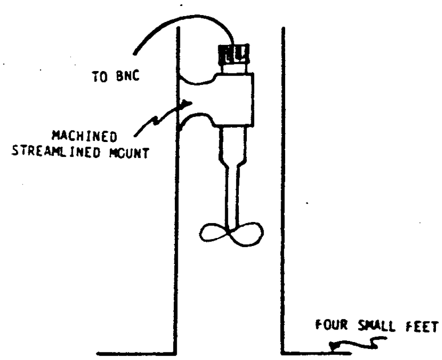


Figure 7. Apparatus (sensor in a large diameter tube) for measurement of vertical airflow.

The system is placed atop the kiln and can be spaced as necessary vertically without significantly affecting the flow rate. Note that with cross flow, vertical spacing can be used to cancel any net flow created in the instrument. Various forms of testing can be made (e.g. cross flow to one end occluded). This system works so well that the high sensitivity manometer has not been necessary.

Two flues represent the output of this kiln and the tops are not accessible at the same time. The kiln is completely capped and the flow guided horizontally through a side port of about 0.45 M^2 to a vertical column of about the same dimensions. This drops the flow into a filter bed of uncooked bricks and up again through another vertical flue of the same dimensions. The first or filter input flue is capped after establishing the flow and the filter output flue continues the process. When the bed is well sealed the buoyancy measurements show that the flow does transfer without significant loss to the second flue. On this occasion measurements of the vertical component were only made after the early capping of the filter input flue. Within the first 40 minutes, the vertical component inside the filter output flue was sometimes as low as 0.3 M/s but increased to about 0.72 M/s. Then the filter input flue was capped. There was a certain amount of patching of leaks on this day. The wind was from the west and the kiln feed port is also on the west. Later and on to 3PM, the vertical component ranged from 0.7 to 2.0 M/s. During most of the early afternoon the value was between 1.26 and 1.62 M/s, within a range that was, in later burns, well substantiated.

Three minute filter-measured average dry aerosol densities for periods of dense smoke averaged, as a group, 0.34 g/M^3 in the roughly half hour before the filter input flue was capped at about 10 AM. After the capping the effluent plume was quite white for about ½ hour indicating that it was largely condensed water. Later, smoke appeared and the three 3-minute filter samples averaged 0.36 g/M^3 between 11:30 and 12 noon but, as we will show, the smoke density increases with time.

From the above results the total dry aerosol flux can be determined quite accurately since the aerosol density is fairly uniform in the 0.44 M^2 flues. Using a vertical flow component of 1.4 M/s we obtain a net dry aerosol mass flow of 0.22 g/s or 13g/min. Since the filter measurements were all made in the midst of feeding cycles (with the aid of the kiln workers) the three minute averages were all quite close to the peak values. Thus, if the flux number given above is divided by three for the stoking and feeding cycle averages, the average flux is about 4 g/min. If we compare this with Don Juan's relatively low flux, the improvement is roughly a factor of 10.

C.Largest of three kilns of Sr. Enrique Chavez, 16 November 1998
Measurement summary: The modified MRI probe included, as for the first kiln measurements, a long, large diameter probe atop a string of close-spaced bricks on brick spacers.Temperatures atop kiln made with Cole-Parmer sensor system, a buzzer was used to locate filters in time for calibration of the nephelometer.
Data: Nephelometer measurements (eventually plagued by condensed water), 12 type AE filter samples were taken, buoyancies, temperatures with time and across surface, aereal coverage by smoke with time,
Fuel: Aserrin (quick burning sawdust).

Performance of this well built, 4.0 M inside diameter kiln is probably typical of the unmodified variety. The feed port is on the east side and in a pit about 2.5 M deep. Lena would have been preferable for comparison with the data already on hand for the modified version but data for aserrin will also be needed. With aserrin feeding is an much more continuous affair as will be seen from the nephelometer data. Variable (and reversible) winds also added some inconvenience even though the measurements did not appear to suffer.

At 8 AM one would have anticipated a calm day. A number of ladrillera plumes were nearly straight up but a west wind (later East) grew to more than 5 M/s. It appears that the kiln was actually started at about 5-6 AM but, at 9AM the active sector atop the kiln was small, as though the process was just starting. Figure 8 is a plot of the smoke development across the kiln output surface with time. As usual the smoke (and temperature) active sector starts above the feed port, here, on the East side. Early winds were from the West.

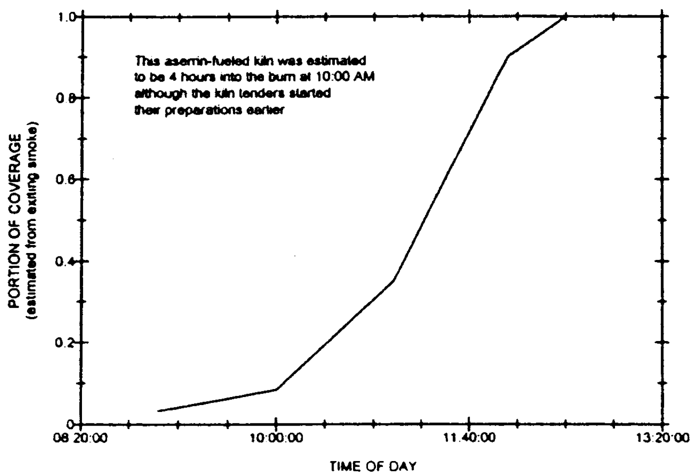


Figure 8. Spatial coverage for smoke: plot of the area involved with time.

It is possible that, on this day, the high (more than 0.6 M) brick rim around the top of the kiln above the top level of the bricks to be cooked and the open sector affected the values of the buoyancy but that is not clear; for intervals of very low wind, they were essentially unchanged. A typical example of the buoyancy spatial pattern on the upper surface of the kiln is shown in figure

9. As you can see the values are lowest in the least smoke-active region; earlier in the cooking cycle they were still lower outside the active region.

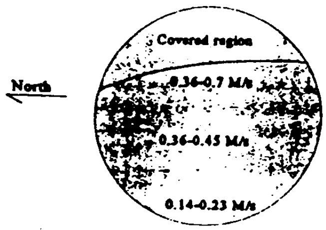


Figure 9. Time averaged buoyancy values across the kiln output surface at about 12:30 PM, approximately seven hours into the burn.

By the time the smoke is fairly well distributed across the kiln top, at 12:30, the workers had begun to cover the kiln top, although the covering does not seem to inhibit the emission of smoke from that region. Figure 9 shows the covered region. After many measurements in the interval 12:30 to about 13:00, the smoke density across the kiln top was essentially uniform. For these conditions the time and spatial average of all buoyancy measurements was 0.35+-0.15 M/s for this kiln. There was no further significant increase in the buoyancy with time.

Smoke (dry aerosol) densities increased throughout the period of the measurements, while feeding was proceeding in a more-or-less constant fashion. Clearly the sampling process should have been continued (as was done for later burns). This burn was initiated much earlier than has been usual (usually 8-9 AM) and so the process was several hours more mature. Nevertheless it was apparent that important developments were still underway .

Temperatures near the top of the kiln are another parameter that always indicate a continuing development in the cooking cycle. At 10 AM, the temperature in the active (East) region was 130 degrees centigrade. At 11 AM the distribution from East to West side by quarters was (unknown at east edge)-149-99-59-26 degrees centigrade. By 12:30 the temperature under the now covered region on the East side was 282 degrees C.

Feeding and stoking for aserrin represent an almost continuous process. Pushing the material in with shovels or pieces of board and then raking it all over with a hoe-like metal tool (having a very long handle) to expose unburned material would seem to cook the operator as well as the bricks. A section of the nephelometer trace, figure 10, shows the close-to-continuity of the process.

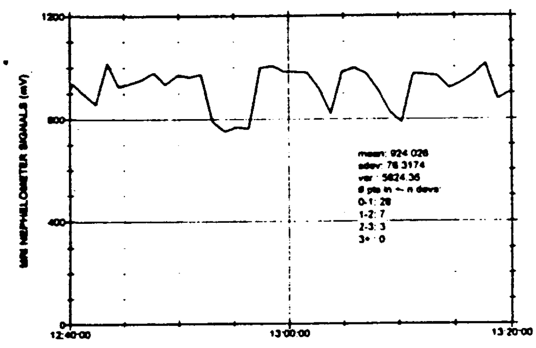


Figure 10. Relative aerosol density time profile for aserrin-fueled burn. It can be seen that the average density is within ten percent of the peak. This was true throughout the burn.

When the results were analysed later the dry aerosol peak densities were seen to have exceeded 1.5 g/M^3 by 11 AM and to be still increasing but measurements were only made to about 1PM on this day. Data to the completion of the cycle would be accomplished on later burns but this value would be seen to be consistent with the maturity of the burn. Using even this value, the total dry aerosol mass flux is

$$dM/dt = 387 \text{ grams/ minute.}$$

Later it will be seen that the typical final value is more than twice this number and that the increase with time is quite linear.

D. Modified kiln of Sr. Enrique Chavez, January 14, 1999

Measurement summary: Two nephelometers placed in line with two pumps (modRAS was on tap-off) in long plastic line to sample within flues, type AE filters, 2 liter gas samples, air flow with Young sensor, temperatures, condensed water caused problems for the two nephelometers.
Data: 15 AE filter samples taken in both flues, measurements made of both water and dry solid aerosol densities, horizontal wind, buoyancies, flue temperatures measured in both flues.
Fuel: Relatively thick lena (pallets).

The only new consideration for this set of measurements may be the preservation and gravimetric measurement of both liquid water which condensed on the filters and solid particulate densities for both flues. Although they will reveal an important trend, it is not clear to what quantitative use these data on condensed water densities can be put. Temperatures of the filter sampling units as used in the flues, for example, are not precisely known. Winds were relatively low. At 10 AM the crosswind ranged from 2.6 to 3.5 M/s and, through midday remained at about 2.5. Near 1 PM the wind speed dropped to zero, changed direction (to East) and increased.

Through the midday Buoyancies developed slowly in the filter output flue. The input flue was capped late on this occasion at about 11:20. Buoyancies in this case increased to about 1.6 M/s within about one hour of capping and proceeded on to 1.76 M/s in less than ½ hour. An increasing East wind this afternoon probably contributed fractionally to the value. The temperature in the filter output flue also increased smoothly from ambient to a value of 59 degrees C by 2 PM with several hours yet in the burn.

Using the Gelman type AE fiberglass filters and the hermetically sealed petris (as usual), both wet and dry weights for the filters were obtained. These filters are always preweighed multiple times in their petris on a Mettler electronic balance. The effects of handling, marking, etc have all been carefully investigated for past research projects. Those elements are not factors at the levels involved in these studies (0.1 - 20 mg) but the issue of petri loss of water (vapor) mass with time was examined in this case. The weights of the sealed petris-with-filters were measured within three hours and then again at 9 AM the following morning. A few percent of the filter mass difference were lost overnight implying that the loss before the initial post-sampling balance measurement was negligible.

From the six measurements in the filter input flue and the nine in the filter output flue, all sample intervals chosen to be in relatively heavy smoke, the following results were obtained:

FILTER MEASUREMENTS

Aerosol densities averaged over the sampling interval (all at or near 3.0 min.

Location of sampler		Liquid Water (mg/M^3)	Dry Aerosols
Filter Input Flue	**(6 ea)**	**261+-71%**	**248+-76%**
Filter Output Flue	**(9 ea)**	**1910+-124%**	**275+-92%**

The percentages simply represent the probable differences between the sampled densities. First, several three minute averages measured in the output flue were between 500 and 600 mg/M^3, which seems to be in the normal range. Second the input flue shows no moisture. This is partly, at least, because the sampler temperature was higher in that flue even though these measurements were made before capping (flue temperature 166 degrees C just before capping). It is also possible that some moisture was accumulated in the underground filter.

The net peak flux for this burn is 0.4 g/s, 24 g/min. A good estimate for the average has and will be shown to be one third of this value.

E. (1) Modified kiln of Sr. Enrique Chavez, March 26, 1999

Measurement summary: New type of aerosol probes constructed to reach through flue walls, penetrate and open when within the flue center, nephelometer heated (heating tape), filters for both gravimetry and SEM, temperatures using both the Cole Parmer system and a new three meter armored thermocouple capable of measuring any temperatures present

Data: Type AE filters used in both flues, 18 type AE filters used.

Fuel: Thin lena

For several hours the site was congested with people of various stripes creating winds and turbulence and making it difficult to make measurements. The new armored thermocouple was used for measurements in three regions. At about 3PM the following temperatures were recorded:

Filter Input Flue	**281**	**degrees C**
Filter Output Flue	**76 - 79**	**degrees C**
Midst of the Fire	**662**	**degrees C**

The construction of the new sampling probes is illustrated in figure 11.

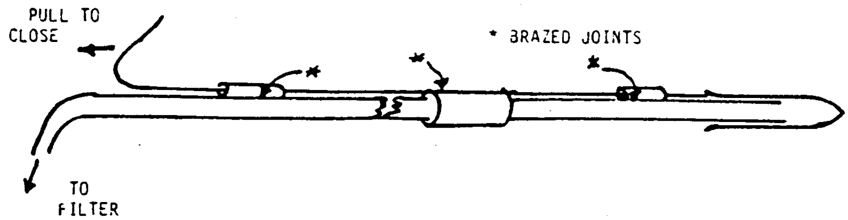


Figure 11. Sampling probes for insertion into the flues of the modified kiln. The tipped cover is controlled by the upper handle while the lower is stainless tubing and terminates in a Swagelok connector (for nephelometer or other sampler. After insertion through the wall of the flue, the tip is pushed away from the sampling tip.

Dry aerosol densities for the filter input flue sampling intervals, which varied from 0.25 to 2.0 minutes, ranged from 0.72 g/M^3 downward with several others between 0.4 and 0.6 g/M^3. The average for the 13 filters was 0.270 g/M^3 which has meaning only in comparison with the average density of the liquid water (36.6 g/M^3). This density is well above saturation for the ambient temperatures.

The output flue this time shows less water for the all filter average at 3.79/ 0.669 g/M^3. And it can be seen that higher peak smoke densities were measured but at later times than for the input flue.

A 2-liter gas sample was taken in the output flue at 3:31 PM

A number of polycarbonate filters were also taken for SEM and EDAX (elemental analyses).

E. (2) Smaller square kiln of Sr. Enrique Chavez, same day
Measurement summary: The same apparati as above.
Data: 11- type AE filter samples, 2-liter gas sample
Fuel: Aserrin.

This kiln, located to the East of the modified kiln, is a square 3M X 3M on the inside. The walls are thin and bulge. It does not fall apart because Don Enrique belts it with wire made taut with bricks pushing against the sides. In other respects it is typical of local kiln construction and the results were expected to compare closely with the last burn of the North kiln which, it will be recalled, most recently burned aserrin. We made a strong attempt in this case to sample entirely in the heaviest smoke periods and the operators cooperated with us in anticipating the correct start times and intervals. The results of this planning is that the measurements were most often very near the peak density envelope. It can be seen in Figure 12 that these results are in good agreement with those previous results, but are well extended in time for this burn.The aerosol density increases approximately linearly throughout the sampling. This smoke, as for the last burn of the North kiln, was impressively thick, like an impenetrable expanding column. .

In the midst of this measurement period a 2-liter gas sample was taken (3:40 PM).

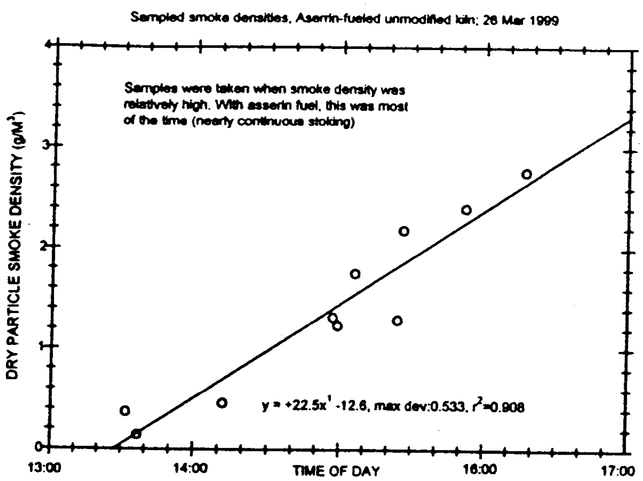


Figure 12. Peak densities for east kiln fed by aserrin on March 26, 1999.

For the visiting kiln operators, an important observation was that, although the modified kiln was within one hour of completing its cycle at 4:30 PM, this East kiln would require another 4 or 5 hours to completely cook its bricks. This latter information was provided by Don Enrique in a conversation with Robert Marquez.

Finally we can compare the dry aerosol fluxes. Appropriate values for the peak densities/ the area/ the buoyancy would be 3 g/M^3 (a minimum) / 9 M^2 / 0.4 M/s to give just about 2/3 of a kilogram per minute peak. If the area for the larger kiln were used the value would be almost one kilogram per minute of largely carcinogenic aerosols lofted and, by the end of the burn it is to be expected that this kiln would achieve that mass flow. The comparable figure for the modified kiln would use the set of numbers (in the same order) 1 g/M^3 / 0.44 M^2 / 1.7 M/s for a peak mass flow of 45 g near the end of its cycle. For obtain an estimate of the averages, multiply by 0.2-0.4.

Clearly there is a factor of 20 here although the differing fuels add a bias..

F. Modified kiln of Sr. Enrique Chavez, April 16, 1999

Measurement summary: For filter and nephelometer sampling within the flues, more apparatus constructed to avoid interaction between liquid water and dry aerosols: for the filter samples a 1/2"by 24" tube; for the nephelometer, a 5/16" tube surrounded by heating tape in turn surrounded by a 1" tube all solidly mounted with RAS which unit is also heated and connected with vacuum pump.

Data: Buoyancy, temperatures, aerosol densities, 17 type AE filters used in Input flue and 15 used in the output flue.

Fuel was wood (lena) but quite thin pieces.

The wind decreased to less than 2 M/s. Buoyancies were lower than usual at between 0.80 and 0.92 M/s with very little variation. Figure 13 shows the levels, fluctuations and statistics for buoyancy measurements for two intervals.Time dependence of aerosol densities, temperatures, gravimetry, wet and dry all produced useful relationships on this day.

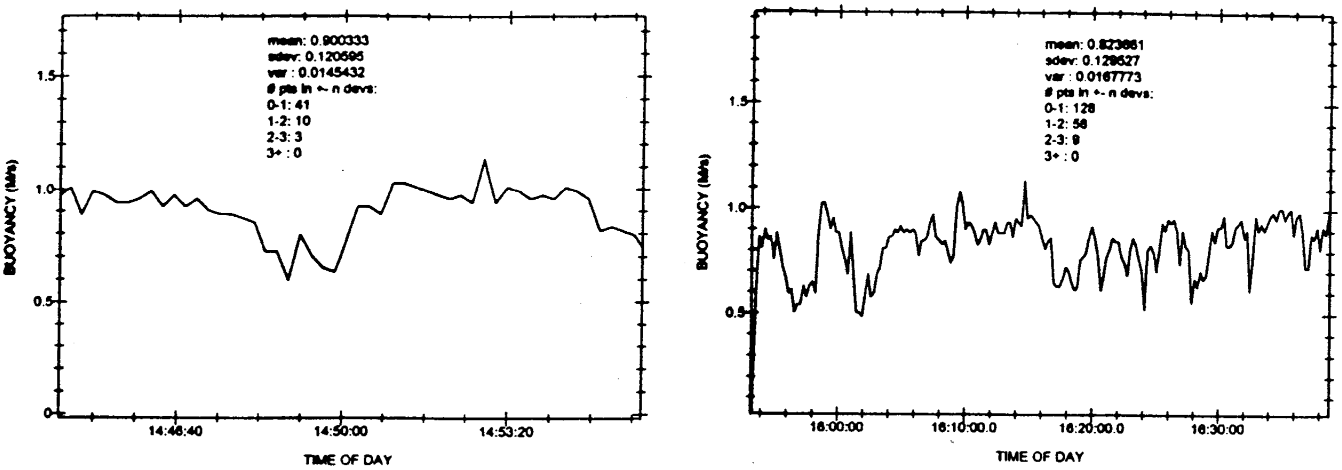


Figure 13. Buoyancies for two intervals on this date.

First, as we have seen before the temperature in the filter input flue continues to rise to the complete end of the burn (but not the cooling-off portion). This is shown in figure 14.

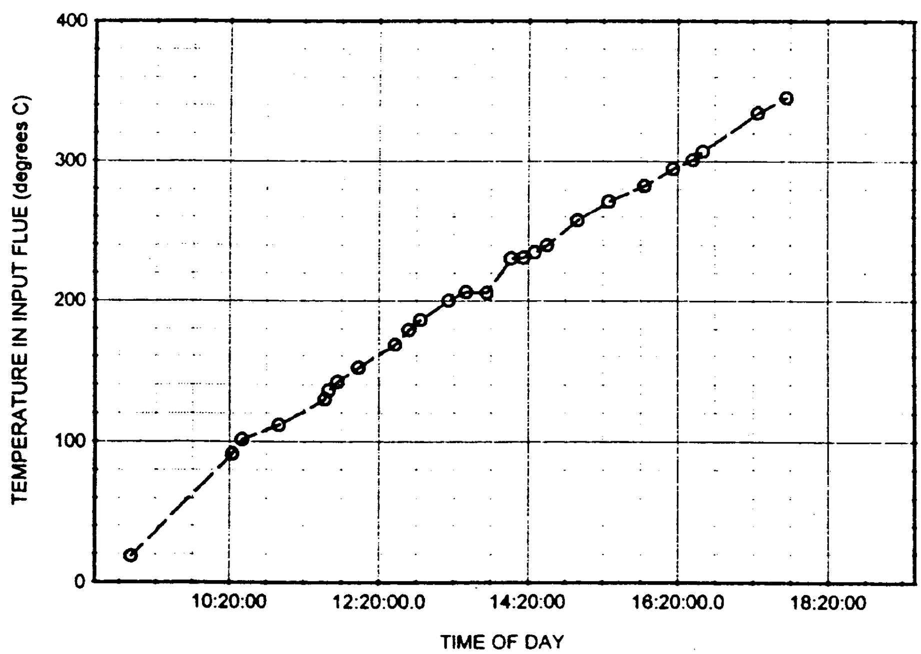


Figure 14. Temperature time profile in the filter input flue for the modified ladrillera, April 16, 1999. The probe was centered in the flue, about one meter from the ground.

The nephelometer, as usual, was calibrated using AE filter data. An example of the comparison is shown in figure 15.

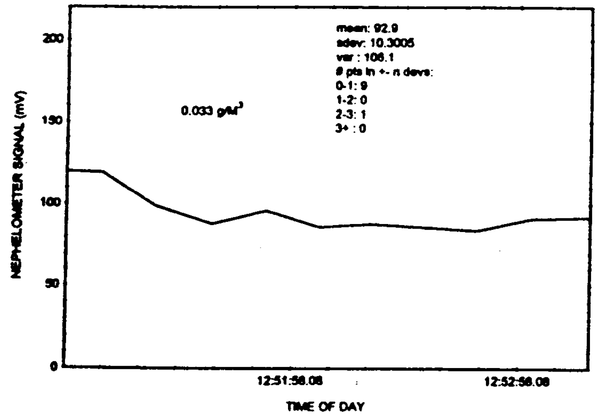


Figure 15. Interval during which filter sample is obtained in proximity with the nephelometer probe. The ratio of the interval averaged density and nephelometer signals forms the calibration constant. The variation for all filter sample intervals indicates degree of accuracy over the range. The systems used are linear over several decades.

The primary importance of the nephelometer data here is to provide good information with regard to the feeding and stoking cycles. An example is shown in figure 16. At some point in this study a large number of cycles were examined to see if times and forms can be modelled and this will be discussed later in this report.

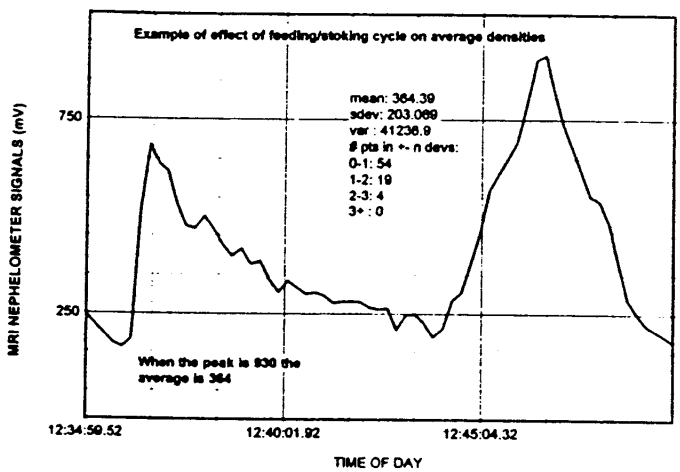


Figure 16. Illustration of feeding cycle form for this burn. These peaks do not show the more typical rectangular form and the tail-off is slower. Forms do vary with operator, type of lena, (thin or thick, for example but often the averages do not vary a great deal Usually for all these results the factor between peak and average is between 0.25 and 0.35.

Here again the dry and wet particulates are separated and, although we cannot be certain, for the moisture, just what the relationship to the sources is, they do tell a story about kiln operation.

First, figure 17 displays a comparison between between the two flues as a function of time gives an idea of filter action.

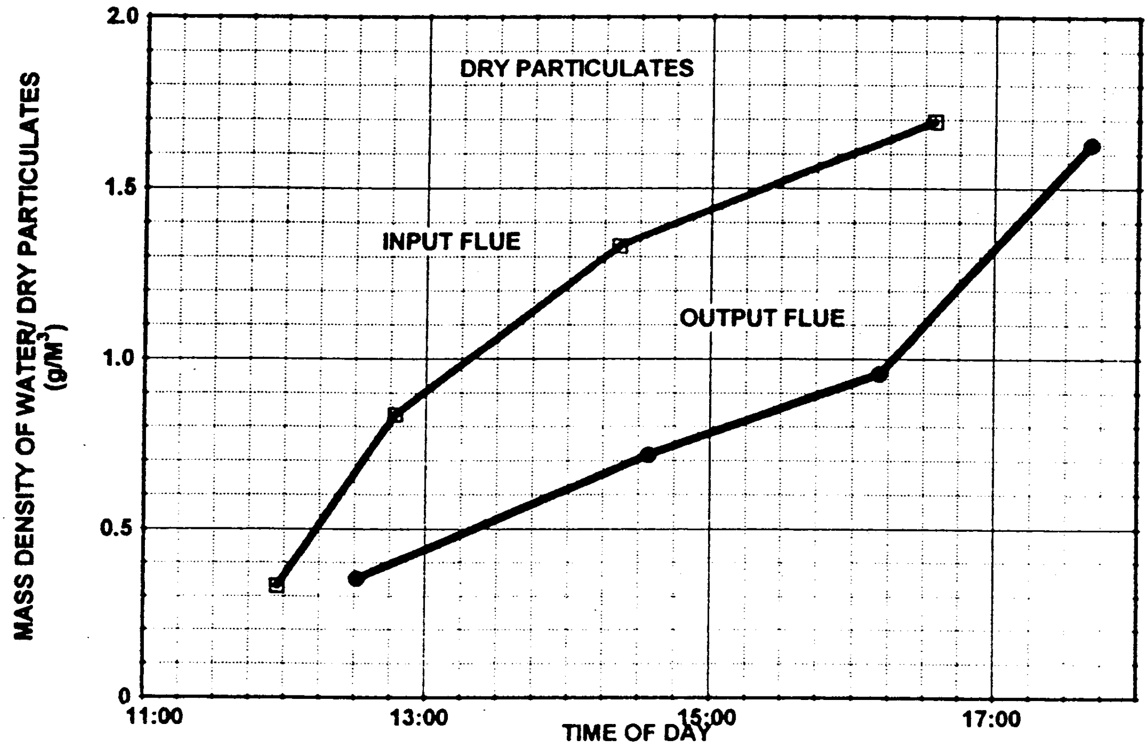


Figure 17. Peak mass densities in the filter input and output flues as functions of time.

It appears from these results that the kiln filter is removing some smoke, perhaps a factor of two in this presentation. This type of exploration of economical filtration is surely the correct direction in which to procede. But it must be noted that the major improvement came from capping the kiln and redirecting the flow. This leads to more even and quicker heating within the kiln, saving money and burning more completely to reduce the flux of hazardous aerosols by more than a factor of ten.

Now another parameter of the cooking cycle is revealed from the separation of water, even though it is not <u>all</u> of the water. Figure 18 shows how the water in the two flues varies within the later cycle, namely that the production of water increases during the cycle, probably much of it coming from the bricks themselves. That seems to be the message of this plot (and not from the fuel nor from the filter!). Nearing the conclusion of the cooking process there simply is not more from that source.: another indicator of completion of the cooking process.

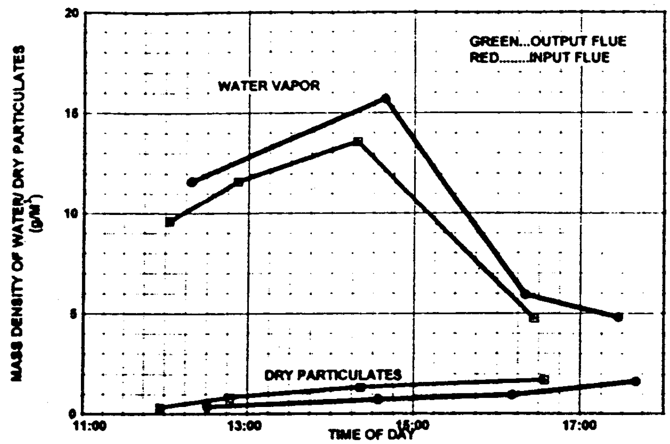


Figure 18. Dry and wet aerosol densities in the two flues. This plot suggests that the water vapor produced is from the bricks themselves. The differences between burns in this respect may indicate, to a degree effects of sun-drying although much of the water may be locked in hydration.

G. Modified kiln of Sr. Enrique Chavez, May 3, 1999

Measurement summary: Modified RAS nephelometer with new aspiration system using computer fan and new baffles, all in one unit this time, usual buoyancies, temperatures.
Data: Buoyancies in input flue (uncapped) and atop north kiln, temperatures (also for capped flue), buoyancy and long term continuous nephelometer data, 12 type AE filters used.
Fuel: lena with (again) relatively thin pieces used.

This time the kiln output was directed through the large (North) kiln, as shown in figure 19, which was filled with bricks (uncooked). In this mode of operation, devised by Robert Marquez, the bricks of the filter kiln might be cooked without reloading and then the process could be repeated in the twin kiln. In this case the north kiln was not capped although it had been modified; a second kiln had been constructed within the first so that the inside diameter became 3.1 M.

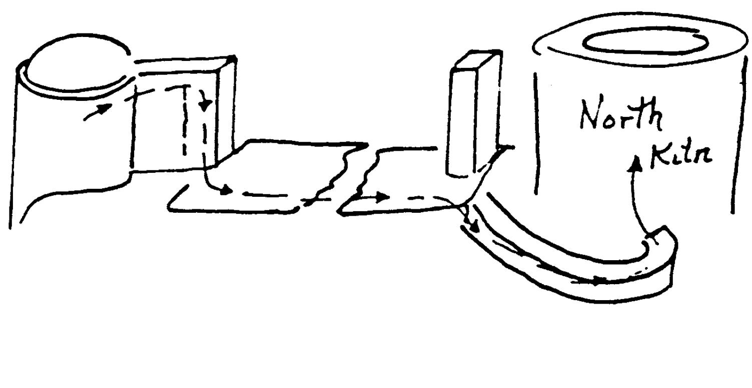


Figure 19. Configuration of kilns and filters used for measurements of May 3, 1999.

For reference to times given, this burn started at about 9 AM. Comparative buoyancies were of interest so measurements were made from within the filter input flue before capping. Results for a typical interval are shown in figure 20. The mean value did not increase from early in the cycle (~10 AM) to shortly before capping at ~11:45. The average value obtained from time intervals prior to capping is 1.48 M/s with probable fluctuations in the 20% range.

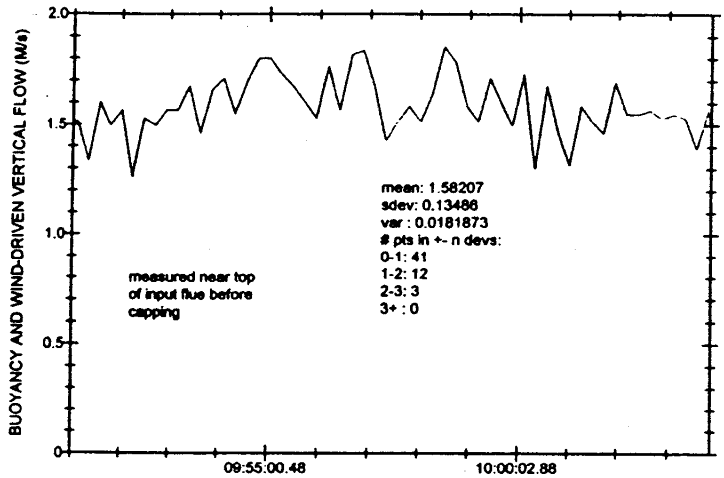


Figure 20. Typical behavior for the filter input flue buoyancies before capping on this date.

After capping, measurements of buoyancies, temperatures and aerosol densities were all made in close proximity in the smoke-active sector atop the second (north) kiln. The active sector was initially a small crescent entirely opposite the feed indicating that the air mass flow rate in the base of the kiln-now-filter carried the material across the chamber. A sketch of this is given in figure 21.

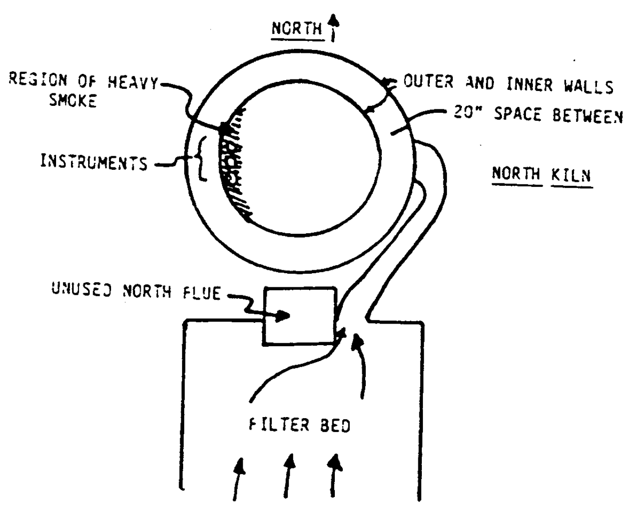


Figure 21. Form of the north kiln which was used as a second filter and its feed system from the first filter bed below the ground. Also illustrated is what was the initial (and for some time) smoke-active sector atop the north kiln. The set of all measurements were in close proximity in that sector. As the active sector expanded, the instruments were moved with it.

Buoyancy atop the second (passive) kiln was initially at the 0.25-0.30 M/s level (for about ½ hour) but developed to and remained at a surprisingly high value near to 1 M/s but the flow was limited to the quite small smoke-active region of the filter kiln surface. There were some small leaks in the underground filter bed but the air mass losses were small. A typical time interval for the buoyancy is illustrated in figure 22.

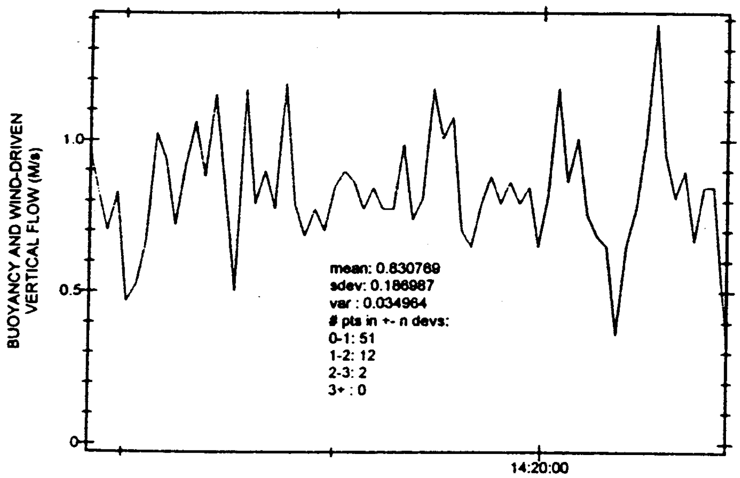


Figure 22. Buoyancies from the smoke-active region atop the filter kiln. When measurements were made in other regions of that surface the values were much smaller as expected.

Temperatures in the central interior of the filter input flue are not much lower than those in the upper levels of the capped kiln and so both relate to development within the kiln. But they also relate to system changes. For example, early in this day, ~9-11 AM, the temperature rate of increase in the flue near the capped kiln (back in the horizontal section exiting the kiln) was greater than it was after capping as is shown in figure 23. After capping the measurement was made a few feet farther along the flue, in the vertical section, but this would make no significant difference in the temperature and certainly not in the rate of increase. Was the cooking process

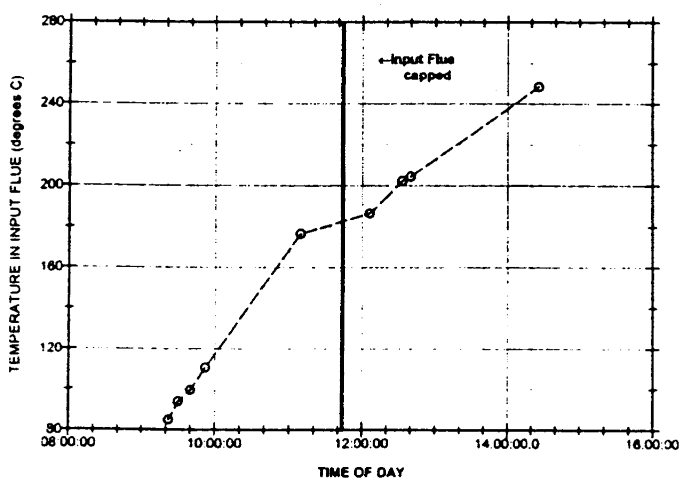


Figure 23. Temperature with time in the filter input flue.

inhibited by the additional flow impedance? As always to date and in our expectations, the upper kiln/flue temperatures increase to the very end of the burn.

There was a wind on this occasion, from the west, and at times strong, especially by 3PM. At other times it was almost calm. It was of interest to determine whether the blowing dust would contribute to the nephelometer signals so the unit was removed from the filter-kiln and placed where it would encounter the scoured dust. This has been done during other burns as well. The answer was still that, as set up for the high density smokes, dust signals were negligible. One one occasion, the dust sampling was done as a function of distance from the ground and , within one foot of the ground, the blowing dust density was significant although, having the same albedo as the ground, it was not apparent to the onlookers. It is always of interest to gain more information with respect to the feeding and stoking cycles and several hours of this were taken on this day. The new configuration of the modRAS nephelometer used to obtain these results is shown in Figure 24.

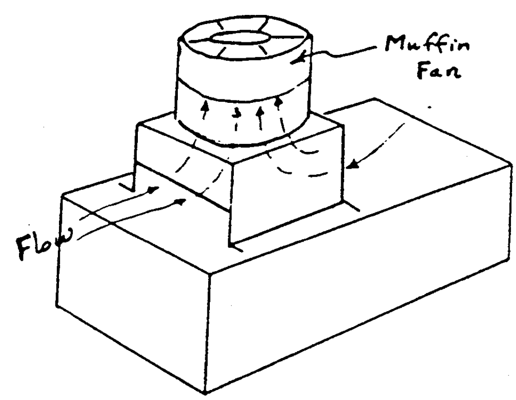


Figure 24. Nephelometer configuration used on this and several following occasions: one more alternative. Here the unit is placed in the region of smoke with aspiration mounted on optical baffles. The unit has proven to be quite tough in use at very high temperatures.

Figure 25 shows two hours of smoke density variations. Note that, after 2 PM the author interfered with the system for a few minutes, to determine effects of smoke particles settling on the optics, so that interval is not indicative of kiln operation. The effect on the recorded densities of those particles that did accumulate was too small to observe.

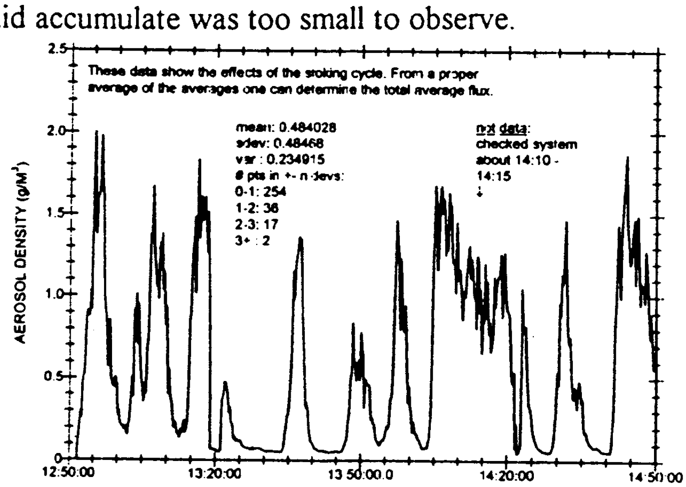


Figure 25. Aerosol density as a function of time in the smoke-active region just above the surface of the filter-kiln

Many filter samples were taken and, for this report, the primary purpose was to calibrate the nephelometer in its configuration for this and succeeding measurements and to determine precision of the calibrating factor. These filters will also be analysed for content.

With a good average for the dry aerosol density, the uncertain factor in the calculation of the flux is the smoke/buoyancy active area. This was determined as accurately as could be and the result was 0.129 X (area) of the inner kiln-filter. The result for the average, valid for about 2 PM is 30 g/minute. As can be seen from the graph, the peak values are about four times that value.

H. East (3M X 3M) square kiln of Sr. Enrique Chavez, May 7, 1999

Measurement summary: The new directly aspirated modRAS was used for the second time.
Data: Aerosol densities using both nephelometers and filters, temperatures were obtained primarily to add feeding and stoking information, 12 filter samples taken.
Fuel: lena.

The kiln operators state that that this kiln burn was started at 4 AM (although it is likely that the actual burn started later at perhaps 5 AM). So, it appeared that these measurements of the early afternoon were being made at a relatively mature part of the cycle. This kiln apparently is less efficient than either the capped one or the double-walled North one (which require more like eight to nine hours) since it was expected that the cooking would not terminate until late in the evening. Considering the maturity, it was a surprise that the temperature under the top layer of bricks in the active area was only 96 degrees C. at 1:30 PM and 154 degrees C at 3:15 PM.

This relatively brief set of measurements (about three hours) were focused on aerosol densities and density cycles. This information will be discussed together with similar data for other burns in the concluding section of the report but smoke peaks tended to be about 1.6 to 1.8 g/M^3 between 1:00 and 3:00 PM without much of a trend and the filter data agreed. Filter sample maxima were between 1.1 and 1.3 g/M^3 for sampling intervals at or near 2 minutes each.

I. Modified kiln again using North kiln as output flue, June 3, 1999

Measurement summary: System similar to that used for the May 3, 1999 burn ...for the same kiln configuration
Data: Continuous temperatures in input flue, 5 type AE filters used for input flue at about the same time as 6 others used for the output flue, buoyancies aerosol densities at output
Fuel: Quick burning scraps from wood working shop.

There was very little interference from the wind (excepting visiting politicians) for this burn and the data should be indicative of this fact. The burn started as it typically does for the modified kiln at about 8:30 AM (because of its relatively short burn cycle) and the first filter input flue was capped at 10 AM. An extended set of buoyancies are plotted in figure 26. As can be seen, the rise of buoyancy to the sustained level was very slow. This is probably because the measuring system was not located in the most active region at the start. Initially, this region uses a quite small portion of the surface, as was illustrated for the May 3 burn Late in the afternoon the smoke active area had increased somewhat to about 40% of the total. It is not clear why this area should have increased with time. The average buoyancy value for this burn is more like the expected value and hints at extactive processes for the previous windier burn.

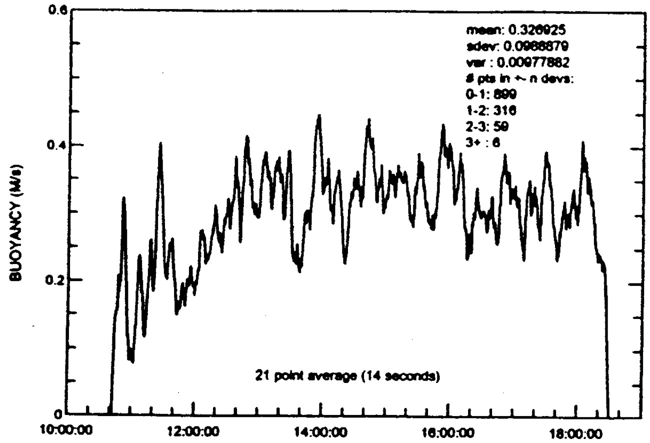


Figure 26. Time history of buoyancies for the modified, double filtered kiln of Sr. Chavez, On June 3, 1999. Values more representative for later times when the active area is more inclusive.

One interesting note is that the lower values of buoyancies tended to correlate with the periods of higher aerosol densities.

Another interesting occurrence concerns the procedure followed by the kiln owner, Don Enrique, on this day. Perhaps because of the presence of all the "visiting firemen", the feed door was carefully kept closed and the thicker lena were used until after the crowd left the site. The feed rate was also observed to be less frequent than usual. Since the cooking cycle tends to be determined by the temperature achieved in the kiln, the author was interested to see what would be the effect of these manipulations. The results are shown in figure 27. There appears to have been no noticeable penalty for having kept the feed door closed and reducing the rate of feed; the rise of the temperature continues linearly.

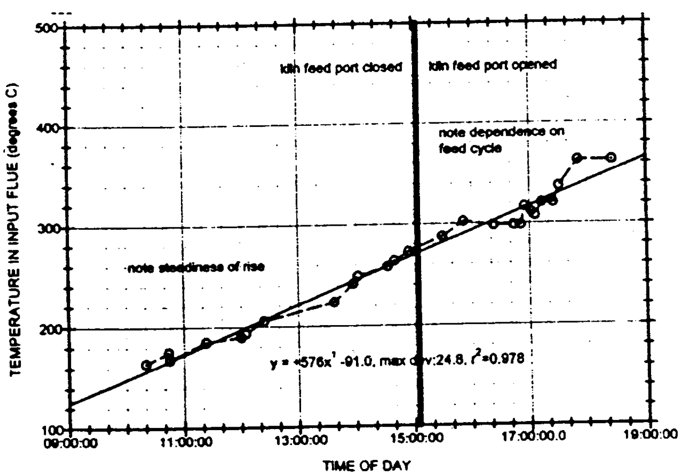


Figure 27. Kiln temperatures in the filter input flue and information on operational effects which should interest the kiln owners.

It can be seen that, after the operation became less controlled, the temperature rise with time simply became more erratic. That the feed was more controlled before the change in mode was first a visual observation and was confirmed by the time plot of the aerosol densities (figure 28). Figures 27 and 28, show, in summary, that carefull practice can significantly reduce the effluent smoke density without cost to the kiln operator and perhaps to his economic gain.

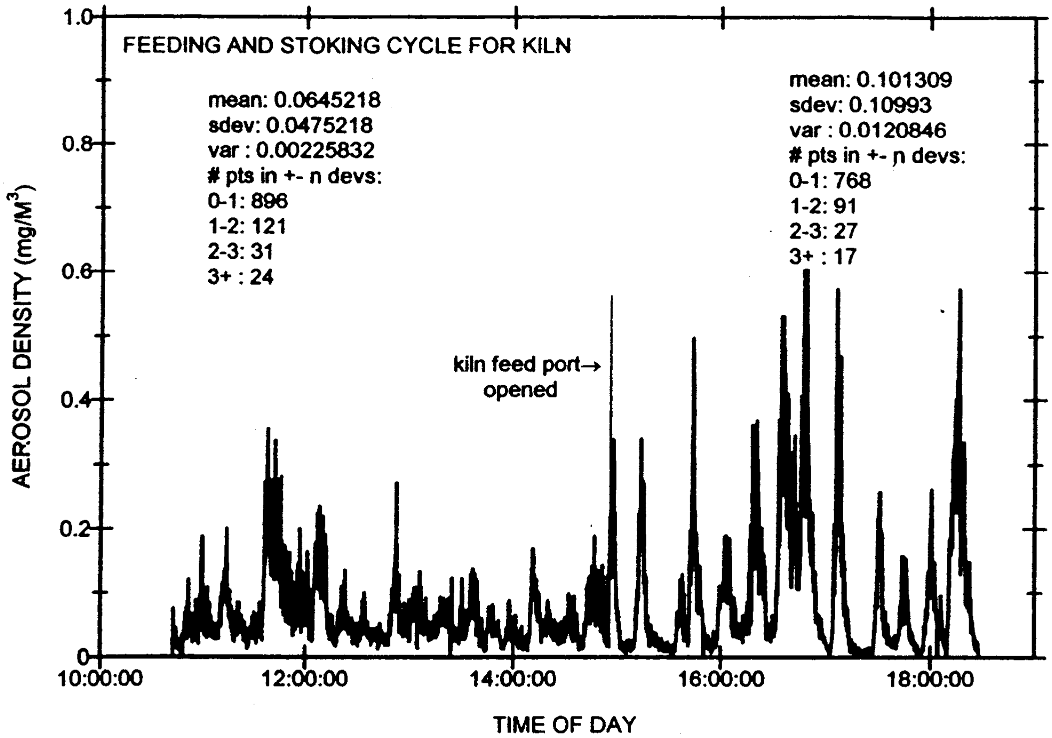


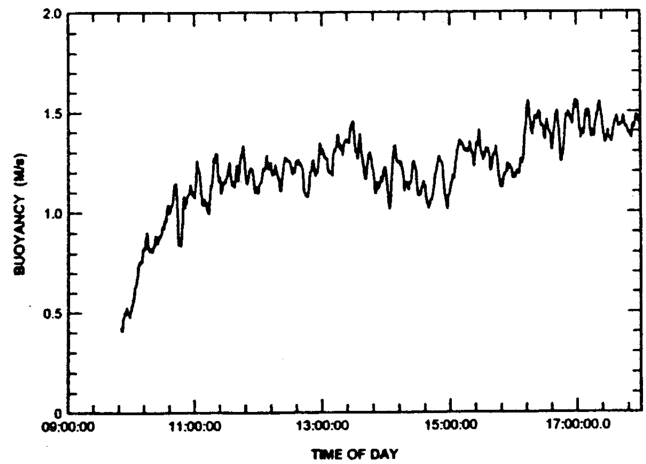
Figure 28. Full day plot of the smoke densities atop the filter-kiln.

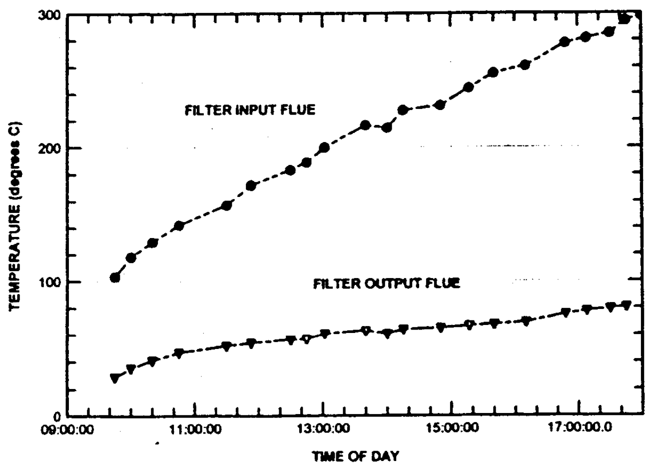
The story for this day must include the results of filter samples taken in both flues relatively late in the burn cycle. These samples were reserved for high density points in the feed or stoking cycle but in fact the operators did, at times, cut the process short so that the filter indicated a lower average density. Between the times 4:10 PM and 4:40 PM the filter input flue peak three minute average value was 2.55 g/M^3 with two of the four others at 2 and 1.5 g/M^3. Just following this, from 4:50 PM to 6 PM, the six samples obtained atop the filter kiln, close to the rim-shielded surface produced dry aerosol densities of 0.29+- 41% g/M^3 with no significant time-trend. Using the same procedures as have been discussed throughout this report, the corresponding peak net dry aerosol fluxes for this burn were 38 +- 62% (s.d.) g/minute for the filter input flue and 6+- 43% (s.d.) g/minute at the surface of the output kiln. The averages for this burn were approximately 1/6 of the peak value. The variances in the numbers above are those of the filter values and do not represent uncertainties in the active area. It appears that the second filter does provide a further reduction in the output flux, of better than a factor of two but of roughly the same magnitude as the first filter.

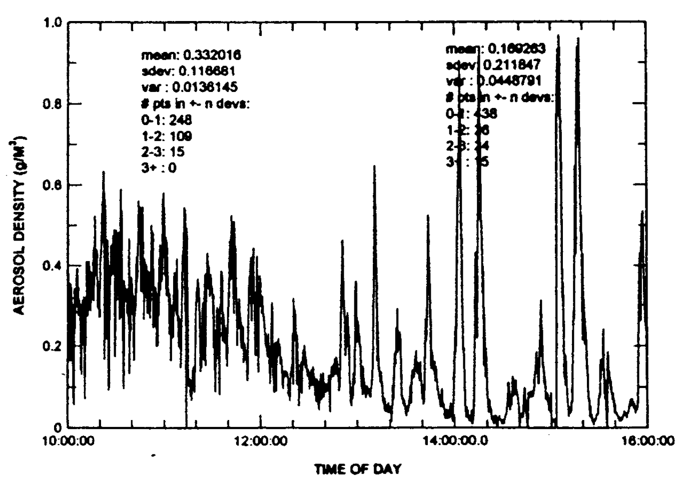
J. Modified kiln using underground filter and 0.44 M^2 flues, July 15, 1999

Measurement summary: same apparatus as for last three burns
Data: time histories for aerosol densities, buoyancies temperatures in both flues
Fuel. lena

The intention on this occasion was to record continuously the four principal values throughout the burn and to obtain a large set of filter samples for the electron microscope analyses. A camera crew and bureaucrats delayed the start but most of the burn is represented. Since the associated issues have been discussed, the variables will simply be presented in figures 29 through 31.







Figures 29 - 31. Buoyancy, filter input and output flue temperatures and net aerosol densities for the modified kiln burn of July 15, 1999.

Analyses of Particulate Samples

SEM analyses from our overall study of ambient air quality (1995, 1997-1999) show a fairly high proportion of ambient air soot content throughout the year (higher in Winter than in Summer) with clays and sand comprising the bulk of the remainder. Soot and clays are also present in the kiln effluent particulate mass along with a higher proportion of ash content than is generally found in the pervasive ambient . Soot, from the photos of figure 32, can be seen to be the prime constituent of the kiln effluent. The soot particles are quite identifiable from their wormlike, convoluted and relatively small forms. The character of soot has been found to be very similar in structure whether created in internal or external combustion (references 4-7). Carbon condenses in small roughly spherical forms (not bucky balls) in proximity with others. These "spherules" (references 5,6) coalesce under what appears to be electrostatic forces (reference 7) and form branched chains as a result of this particular force. The growth process is then completed and the result looks somewhat as though the chain of spheres was dipped in molasses. Statistically, these particles are well described as fractals by a single fixed parameter.

The mature diameters of the spherules range between 0.03 um and 0.06 um and the complete branched chains can exceed a dimension of 1um. The content, then, is free carbon but these relatively small fibrous particles are often nuclei for larger liquid droplets. For petroleum fed fires (either by external or internal combustion) the soot particles are coated with liquid hydrocarbons (reference 7, for example). Perhaps together with the coatings, soot has long been understood to be a strong carcinogenic agent. Therefore we are all concerned when elevated densities of this material appear in the air in which people live.

The remainder of the solid particulate material might be placed in a general category of respiratory irritants, especially those that fall in the well known "respirable" range (from diameters of tenths of a micron to diameters of several microns) which cause damage. Note that soot is excluded from this range of questionable utility.

Although the analyses of kiln particulate composition are still underway, a typical example of the atomic composition of solid particulate effluent, this from an unmodified kiln, can be seen in the EDAX trace in figure 33. From spectra such as this semiquantitative composition of the constituents is being obtained. Carbon is of course strong; certainly most of it is free carbon. Silicon, which appears in virtually all clays as well as in sand and constituents of various minerals are present although aluminum is quite low and iron is not seen here.

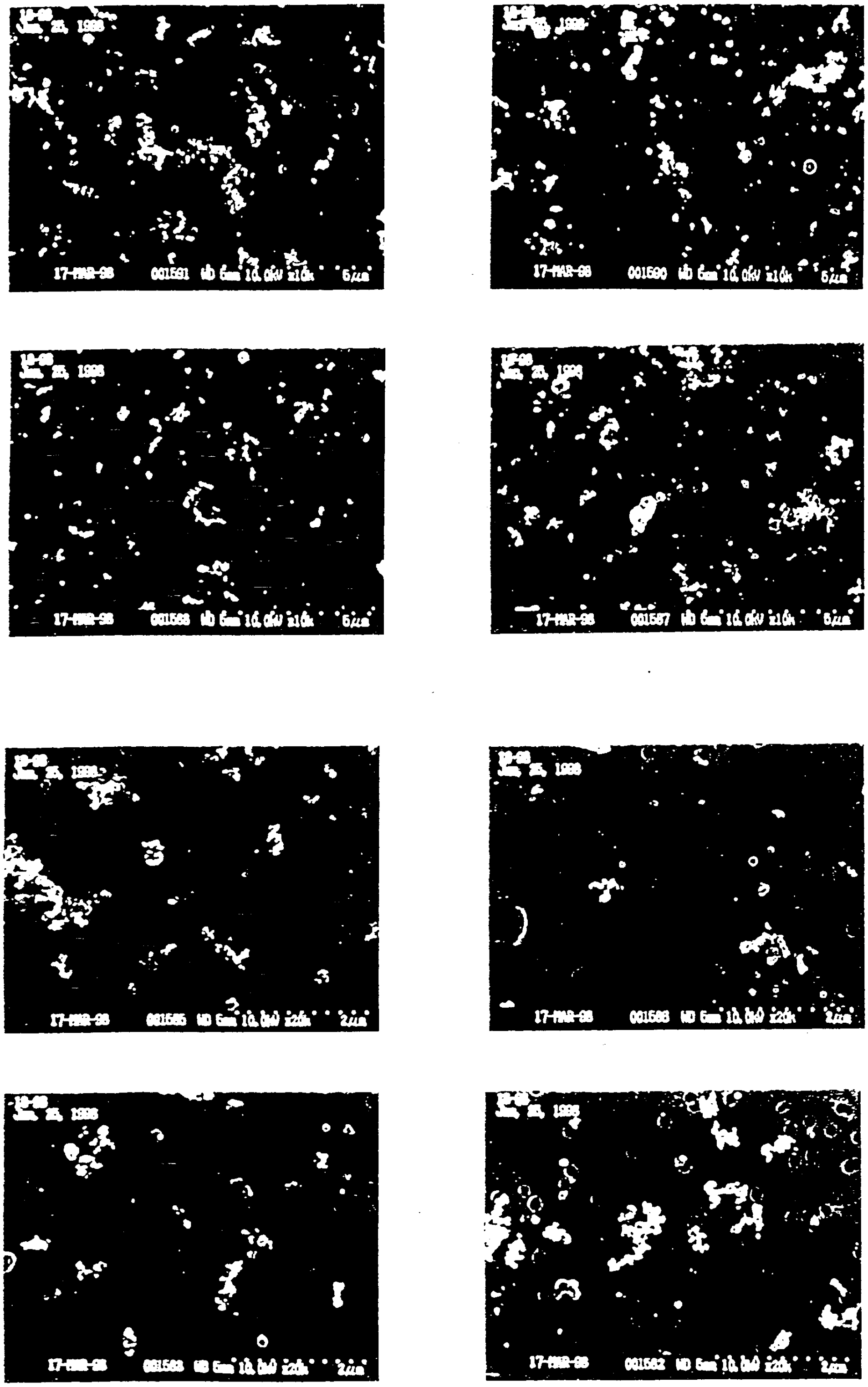


Figure 32. Photos of kiln effluent particles, "burn" of 17 March 1998: (a) four photos magnified 10,000X in the original photo and, (b) four photos at 20,000X. The actual sizes are indicated on the photos.

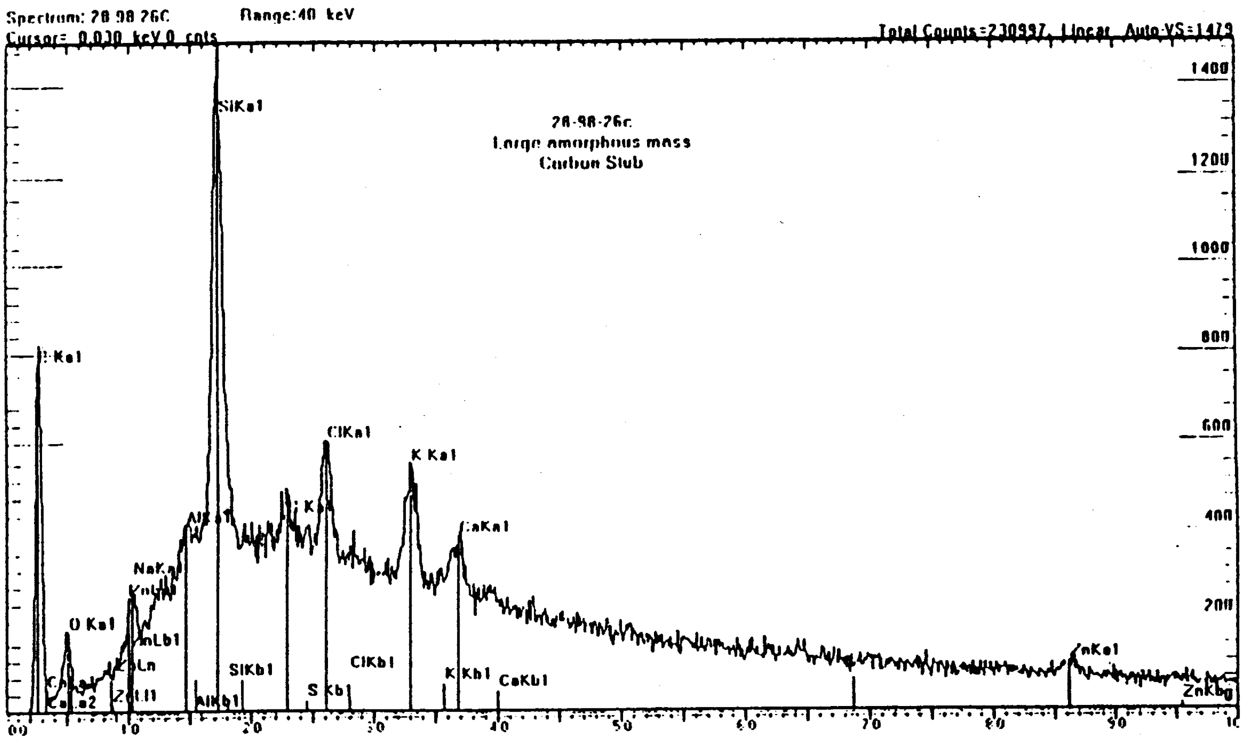
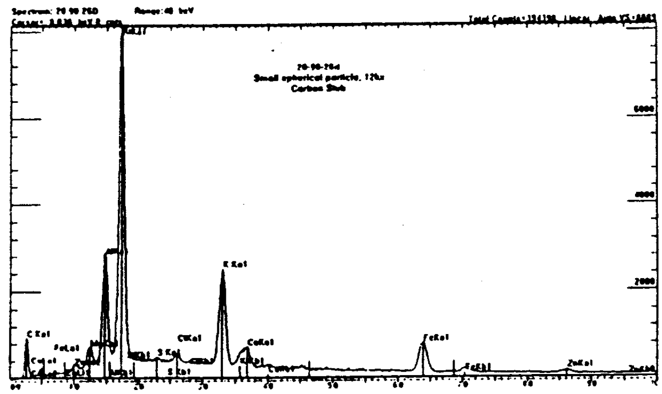
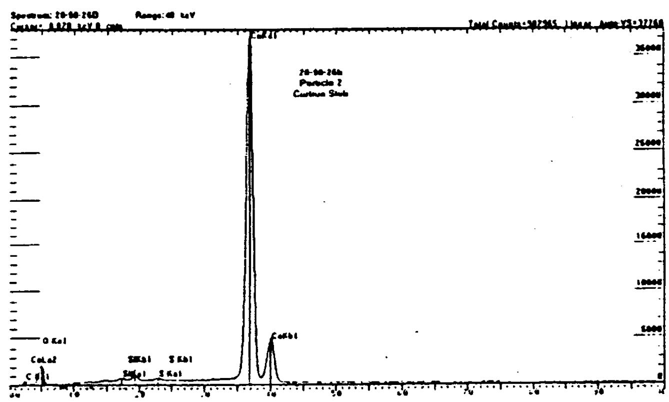


Figure 33. EDAX spectrum of mass on fiberglass filter; fiberglass filter spectrum has been subtracted.

The last figure (34) simply shows several EDAX examples indicating constituents of specific effluent particles. The particles of figure 34a and 34c show the aluminum and trace iron that are usually found in clays.





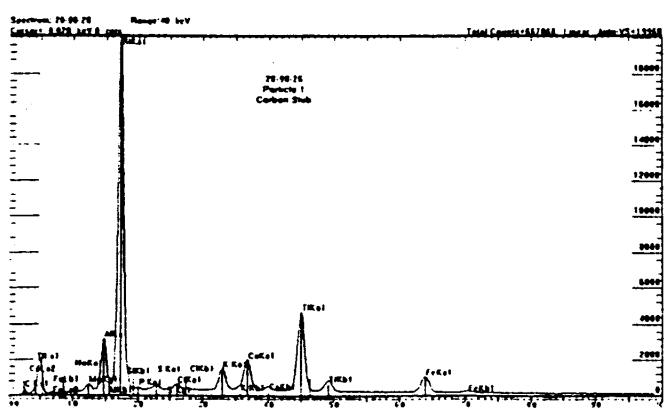


Figure 34. EDAX spectra indicating elements present in various individual particles.

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APPENDIX I

Summary of Measurement Systems

A. Filters:
1. Gelman type AE fiberglass
   Uses: gravimetric, atomic analyses (EDAX)
2. Polycarbonate (PC) from various sources, pore sizes 0.1 and 0.2 um
   Uses: electron microscopy of particle morphology, atomic composition (EDAX) of individual particles

B. Nephelometers (volume scattering)
1 .Much Modified MRI model 1550B, (now) Belfort Inst. Co. for basic unit. Unit as used described in reference x.
2. Modification of GCA Corp. model RAS. Developed at request of author under joint EPA/ USArmy contract # 68-02-3168 for field measurements of aerosol densities of a wide variety of aerosols. Testing and development for field use of all 40 units performed in author's laboratories.

C. Temperature measurements
1. Cole -Parmer high temperature unit with indicator
2. Stainless, flexible, ceramic-insulated 3 M long probe by Omega

D. Buoyancy measurements
1. Acoustic manometer developed by author (reference 2, 2 patents). Extremely sensitive but overkill. Used only for first burn. Primarily used in author's wind tunnel to verify system described below..
2. Tube-mounted Young wind sensor, Young sensor selected for lowest stall speed.

E. Gas sampling
   Two-liter stainless steel sampling bottles with stainless hardware (5 available). Bottles baked, pumped extensively and reference measurements made. In use These were preceeded by h double filters.

F. Others (e.g. video, photos, dimensions, visual of kiln-top area involved with time...etc)