MEETING AIR QUALITY STANDARDS IN THE FOUNDRY INDUSTRY
A STUDY OF FOUR PENNSYLVANIA FOUNDRIES

John W. Davis
Assistant Professor of
Industrial Engineering
Center for Air Environment Studies
The Pennsylvania State University

Vernon C. Irwin
Research Assistant
Center for Air Environment Studies
The Pennsylvania State University

Kenneth Knott
Assistant Professor of
Industrial Engineering
The Pennsylvania State University

ABSTRACT

This is the report of a study of four operating foundries conducted by The Pennsylvania State University. The overall purpose of this effort was to assess the occupational health problem associated with atmospheric free silica in the foundry workplace and to examine one solution to the problem, namely, the substitution of a non-silica based sand for silica sand in the molding area. Work began in 1976 and lasted a little over two years under the sponsorship of the participating foundries in cooperation with the office for Small Industries Research of the Pennsylvania State University.

Results indicate that the use of a silica sand substitute, olivine, which contains little or no free silica, does improve the air quality. Even in mixed silica and olivine sand systems improvements were noted. The number of standards violations was greatly reduced and there are indications that the levels of respirable particulate went down.

INTRODUCTION

There are many occupational health and safety problems associated with foundry operations. The one about which there has been continuing concern is air-borne crystalline free silica. This substance is known to have a deleterious effect on human health. Studies indicate that persons exposed to silica dust over extended periods of time can develop silicosis and this disease can be disabling (1, 2, 3). Control of this problem has been of primary concern to federal agencies and a vigorous program has been initiated to bring foundries into compliance with regulations.

There are three major methods of control available to foundrymen. First, and most effective, is isolation. If the workers can be removed from those areas in which the silica dust is in the atmosphere, no exposure can take place. This solution requires complete mechanization so that the molding, pouring, shakeout and initial clean-up of castings is done with little or no human involvement. Economically, this is feasible for only a small group of foundries in the industry.

Air extraction is probably the most popular approach to control. Exhaust systems must be designed, installed and maintained so that the respirable particle matter is efficiently removed from those areas in which work stations are located. The design of such systems is critical. Large sums of money can be (and have been) spent and control of the respirable particulates still not be achieved. Systems improperly maintained or maintained only when inspectors are present may not provide continuing protection to foundry workers. The extraction systems are costly not only in the purchase of capital equipment, but also in the continuing expenses for energy and maintenance.

A third solution is to substitute for silica sand a molding material that does not contain free silica. Olivine is such a material. It has been used in Scandinavian countries for many years in foundry operations. The health studies which have been done to date indicate that olivine is less injurious to health than silica sand (4, 5, 6). Clearly, any air-borne particulate in sufficient respirable quantity is not desirable in the workplace, but one with minimal effects is to be preferred. Olivine is approximately five to six times more expensive than regular molding sand to purchase, but it does give excellent quality castings which require less surface grinding. In addition, much less make up material is needed since it does not break down like silica sand.

A research study was initiated at the Pennsylvania State University to study the air extraction and sand substitution solution to the free silica problem in foundries. Work began in 1976 and lasted a little over two years under the sponsorship of the participating foundries and the office for Small Industries Research of the Pennsylvania State University. In most situations olivine would be introduced into a mixed system; that is, the foundry would not totally abandon the use of silica sand, but continue to use it in core-making and/or air-set mold (or no-bake) systems. This means that, since the silica sand cores are ground up and reconditioned with the molding material for re-use in molding, contamination of the olivine with silica is inevitable. The question was whether the respirable free silica levels would be reduced in such mixed systems to levels that would meet the regulations.

DESCRIPTION OF PARTICIPATING FOUNDRIES

Table 1 shows the basic characteristics of the foundries involved in the study. All four were gray iron foundries and produced a variety of different types of castings. While plant layouts and the amount of mechanization varied somewhat, the air quality problems were shared by all participants. Their collective concern over the occupational health problem was such that they were willing to invest funds in this research program.

Table 1. Characteristics of participating foundries.

Foundry designation	No. of employees	Amount of metal poured		Size of castings		No-bake	Molding	Shakeout
		Metric tons	Tons	kg	lb			
A	50	13.6	15	0.5-454	1-1000	Yes	Hand Ramming Squeeze Mach.	Hand operation
B	50	10.9	12	0.5-454	1-1000	Yes	Hand Ramming Squeeze Mach. Slingers	Hand operation
C	75	18.2-63.6	20-70	0.5-908	1-2000	No	Hand Ramming Squeeze Mach. Rotolifters	Hand operation
D	250	109	120	0.5-908	1-2000	No	Hunter Automatic Disamatics Squeeze Mach. Rotolifters	Automatic

Foundry A substituted the mineral olivine for regular silica sand in the molding area. One test was conducted prior to the changeover and three afterwards. At Foundry C, olivine was in use and for technical reasons the operator decided to switch back to silica sand; one test was made at each condition. At the other two foundries only one set of tests was obtained. Foundry B was essentially an uncontrolled situation from a ventilation standpoint and Foundry D had installed a fairly large air extraction system.

NATURE OF THE AIR QUALITY STUDY

The major purpose of the study was to assess the impact on air quality of substituting the mineral olivine for the regular silica based sand. In addition, it was also of interest to examine the air quality in an uncontrolled shop and one which had tried to solve the free silica problem by air extraction. The economics of the solutions are discussed elsewhere (7).

Another aspect of the work discussed in the earlier stages was casting quality. It became apparent after the initial study in Foundry A that the quality of the castings made with olivine molds was quite comparable to those cast in silica sand molds. This particular parameter was best evaluated by the individual foundry with their own specific requirements.

Air quality was measured in three ways. The standard personal sampler was used on individuals. Cascade impactors, located at various points within the foundry were operated at random intervals in order to obtain particle size distributions. Tape samplers were located in five areas of the plant and were run continuously during the study; this permitted hour by hour evaluation of the air quality. In all cases, samples were taken over one week periods. Table 2 indicates when and how many samples were obtained of each type.

Table 2. Sampling summary.

Foundry designation	Date	No. of personal samples	No. of impactor samples	Tape samplers, continuous
A	October, 1976	35	24	5
	January, 1977	30	21	5
	August, 1977	28	16	5
	November, 1977	15	18	5
B	February, 1978	19	35	5
C	September, 1978	18	23	5
	November, 1978	19	21	5
D	October, 1978	23	29	3

SUMMARY AND DISCUSSION OF PERSONAL SAMPLER DATA

The personal samplers used were from several manufacturers. Two types of samples were taken: 1) the standard procedure was to use the nylon cyclone with a back-up millipore filter and, 2) on occasion the filter holder was expanded to three sections and a sample taken without the cyclone to give a total dust reading. The data for each foundry was compiled by area. The percent quartz was determined by the Bumstead x-ray diffraction method.

In order to compare the air quality as measured by the personal samplers, the data are presented in two ways. Table 3 summarizes the number of OSHA violations - the measurements where the Time Waited Average (TWA) exceeded the Permissible Exposure Limit (PEL) for respirable silica dust* by area in each foundry. Within the table, the samples taken when Foundries A and C were on olivine are shown separately. A second method of presenting the same data is shown in Table 4. In this case the averages of the ratio of TWA to PEL are shown for each area and each foundry. The larger the ratio, the more likely there is to be a violation. It should be noted that a ratio less than 1.0 does not mean that a violation is impossible, only that it is less likely. Numbers larger than 1.0 indicate the violations will definitely take place.

Table 3. Summary of personal sampler violations for respirable silica.

	Using silica molding sand							
	Molding area		Grinding area		Core area		Shakeout area	
Foundry	N	Violations	N	Violations	N	Violations	N	Violations
A	9	1	10	4	10	3	6	2
B	8	2	5	4	2	0	4	2
C	9	8	3	1	1	1	5	3
D	14	8	6	6	3	1	No separate shakeout	
	Using olivine molding sand							
A	23	0	13	5	15	2	10	0
C	11	1	3	0	3	0	2	0

Table 3 indicates that these four foundries definitely have problems in violating OSHA standards when a silica molding sand is used. In Foundry D, where a large investment in air extraction equipment has been made, the problem is acute. It should be recalled that this foundry also has the highest degree of automation (see Table 1).

When olivine was used in Foundries A and C, reductions in the number of violations were clearly achieved, but violations were not eliminated. Both foundries had a mixed system of silica sand and olivine. Silica sand was used for cores and, in the case of Foundry A, there was a large no-bake area adjacent to the molding floor where both air set cores and molds were made. If one looks at the use of sand substitution from the regulatory point of view, there is still a risk of OSHA violations, but the risk is somewhat reduced.

*OSHA PEL for respirable dust containing quartz is calculated as $\frac{10}{2+\%\ \text{quartz}}$.

The grinding area is the exception to this rule because of the high particle concentrations in that area; if castings from air set molds are ground, the percent quartz can still be quite high. Foundry C had grinding booths and lower overall dust concentrations in that area than any of the other three foundries. The shape of the castings at Foundry A made the use of booths somewhat impractical. The problem of violations in grinding was not controlled by changing to olivine for molding.

Table 4 indicates the same results in a numerical way. Note again that the foundry (D) with the highest level of automation had the most difficult control problem in both the grinding and molding areas. The value for TWA/PEL ratio in the core area was similar to the ones found in Foundries A and B. The single value for Foundry C in that area is probably erroneous.

Table 4. Summary of personal sampler results for respirable silica.

	Using silica molding sand							
	Molding area		Grinding area		Core area		Shakeout area	
Foundry	N	TWA/PEL	N	TWA/PEL	N	TWA/PEL	N	TWA/PEL
A	9	0.61	10	1.14	10	0.98	6	1.09
B	8	0.90	5	2.13	2	0.88	4	1.22
C	9	2.05	3	0.97	1	4.42	5	1.01
D	14	2.70	6	3.25	3	0.92	No separate shakeout	
	Using olivine molding sand							
A	23	0.40	13	0.90	15	0.43	10	0.23
C	11	0.44	3	0.50	3	0.60	2	0.28

At foundries A and C the two areas which should be most affected by the use of olivine are molding and shakeout. When silica sand is the molding material, higher levels of quartz are found and the PEL is smaller as the result. The ratio of TWA to PEL would, therefore, be larger and should show a statistical difference when compared to the same ratio when olivine is in use.

To compare two sample means where the sample size is small ($n < 30$) the student t test is used. The null hypothesis

$$H_o : \mu_1 = \mu_2$$

indicates that the means are equal. Clearly, this should be the case if the samples are drawn from the same population. A 95 percent significance level is used for the test.

The input information and the results are shown in Table 5. Note that in three of the four cases the hypothesis that the means of the population are equal is rejected. In the case where the sample size is extremely small (2) the hypothesis cannot be rejected.

Table 5. Statistical test.

Foundry A TWA/PEL (Silica)				Foundry A TWA/PEL (Olivine)		
$\bar{X}$	S	n		$\bar{X}$	S	n
0.61	0.325	9	Molding area	0.404	0.170	23
1.098	0.812	6	Shakeout area	0.225	0.150	10

Foundry C TWA/PEL (Silica)				Foundry C TWA/PEL (Olivine)		
$\bar{X}$	S	n		$\bar{X}$	S	n
2.05	1.359	10	Molding area	0.424	0.296	11
1.01	0.417	5	Shakeout area	0.285	0.236	2

Degrees of freedom	$t_{0.05}$ level	t calculated	Designation	Hypothesis
30	1.960	2.358	Foundry A Molding	Reject
14	2.145	3.381	Foundry A Shakeout	Reject
19	2.093	3.878	Foundry C Molding	Reject
5	2.571	2.236	Foundry C Shakeout	Accept

While this is not a conclusive test, it is an indicator that the introduction of olivine reduces the TWA to PEL ratio significantly. This in turn should reduce, but probably not eliminate, the possibility of a violation of OSHA regulations in the Molding and Shakeout areas or in any location in the foundry where olivine is in use.

SUMMARY AND DISCUSSION OF IMPACTOR RESULTS

The cascade impactor is an instrument that has been widely used in assessing air quality in all types of atmospheres. An Andersen unit was used in these studies. It was originally designed to simulate the human bronchial system. Particles are drawn into the device at a fixed flow rate and are fractionated into size ranges by progressively increasing the velocity and collecting a fraction at each stage. The collection media are weighed before and after exposure to determine the amount of material in each fraction. Results can be plotted in many ways. Differential plots were chosen since they present the data in a pictorial way.

Figure 1 shows the data from the molding area of all four foundries. Each curve represents at least five impactor samples taken at random intervals in each foundry. The similarity of the curves is obvious. The ordinate is labeled DM/D Log DP. This means the change in the percent mass divided by the change in the log of particle diameter. To put this more simply, the area under the curve between any two selected particle sizes on the abscissa represents the percent of the mass in that interval.

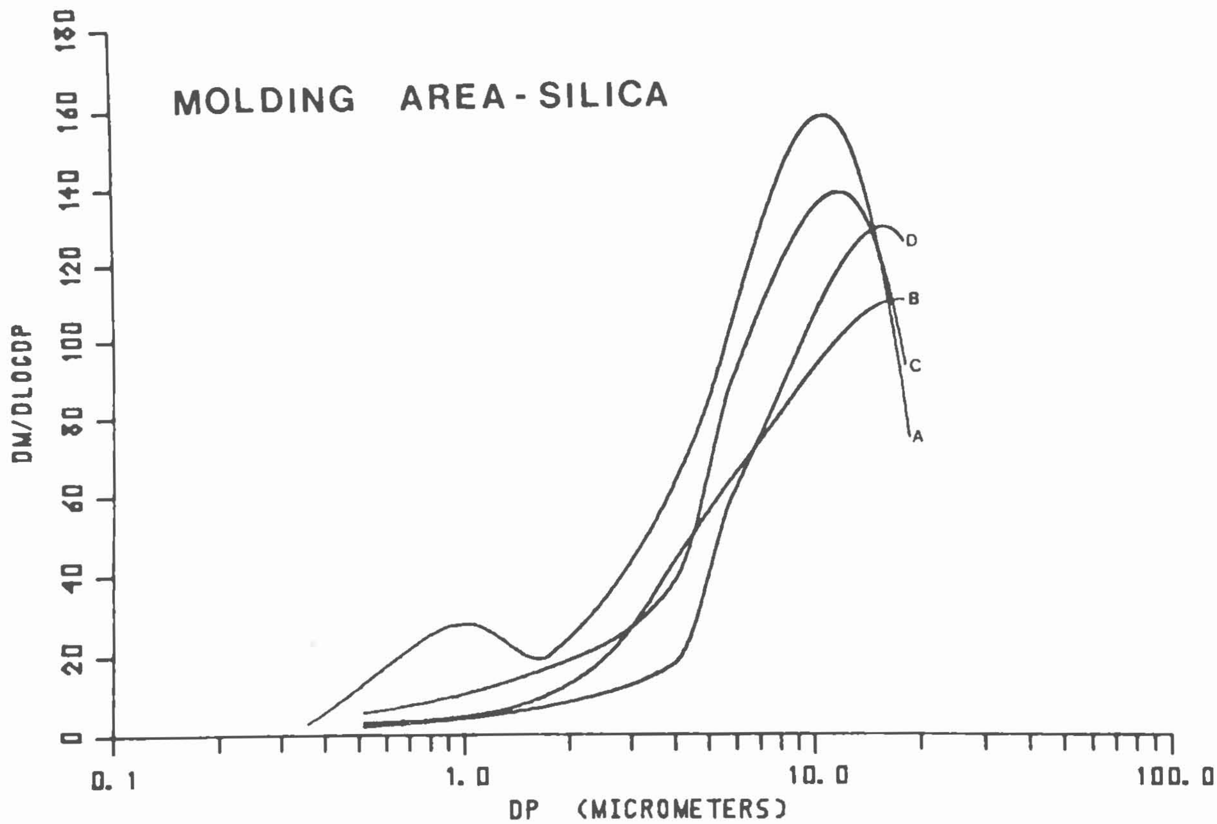

Figure 1. Molding area impactor plots.

The curves that are shown are characteristic of all areas of the foundry. In the complete report of this work the distributions by area for each of the participating companies are shown (7). These data indicate that the largest population by mass of the airborne material is larger than 4.0 micrometers. There is still a large fraction of the dust in the respirable region (~<2.0μm) and this, of course, constitutes the basic occupational health problem.

Since olivine is more dense than silica, it should tend to settle out more quickly. More importantly, because of its physical characteristics, it is also less likely to fracture at the mold surface where high temperatures are present. The point at which some of the free silica is generated in foundry operations is at the point where the hot metal comes into direct contact with the silica sand. Olivine does not fracture to the same extent at this surface and one would assume that the concentration of very small particles should be less in an olivine system than in a silica sand shop. In the two foundries which used both silica and olivine, the point at which this factor should be most noticeable is at shakeout. When the molds are broken to remove the castings, large amounts of fine particles become airborne.

Cascade impactor tests were taken at shakeout in Foundries A and C when both silica and olivine were in use. Figures 2a and 2b are plots of these data. In this case the ordinate is labeled DC/D Log DP.

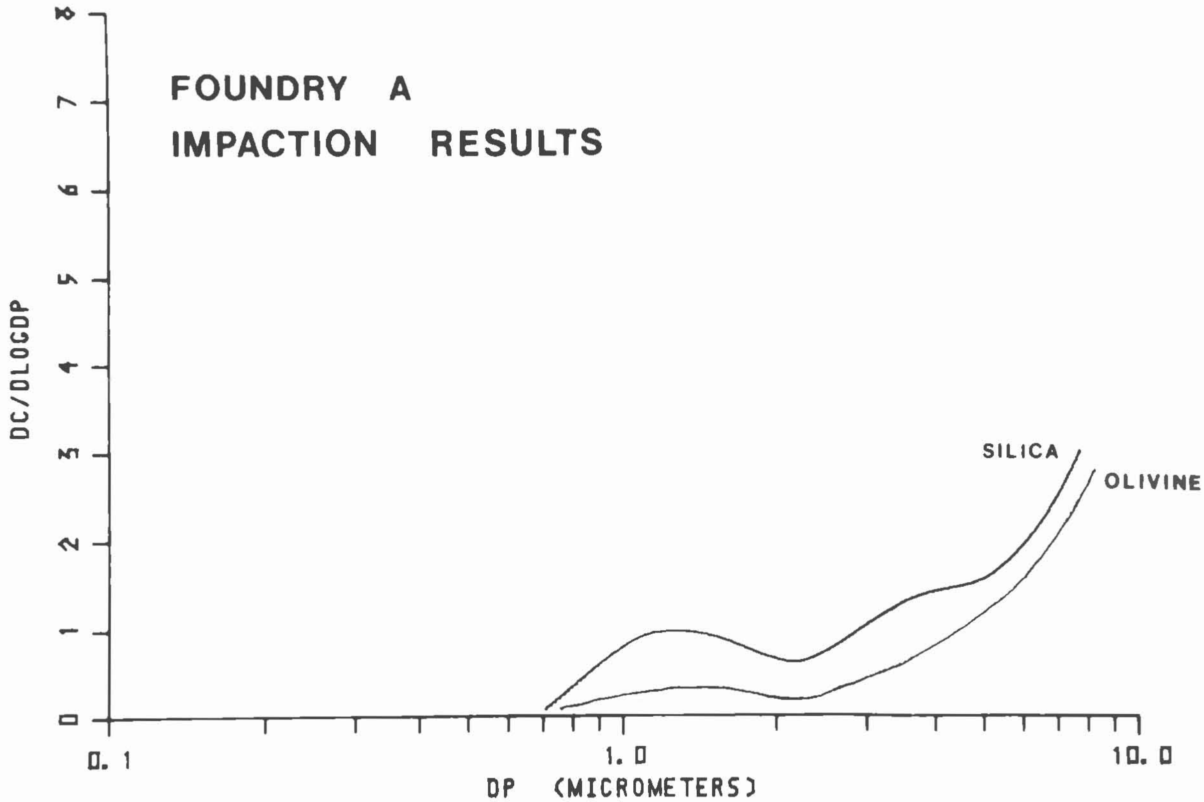

Figure 2a. Impaction results, shakeout area, Foundry A.

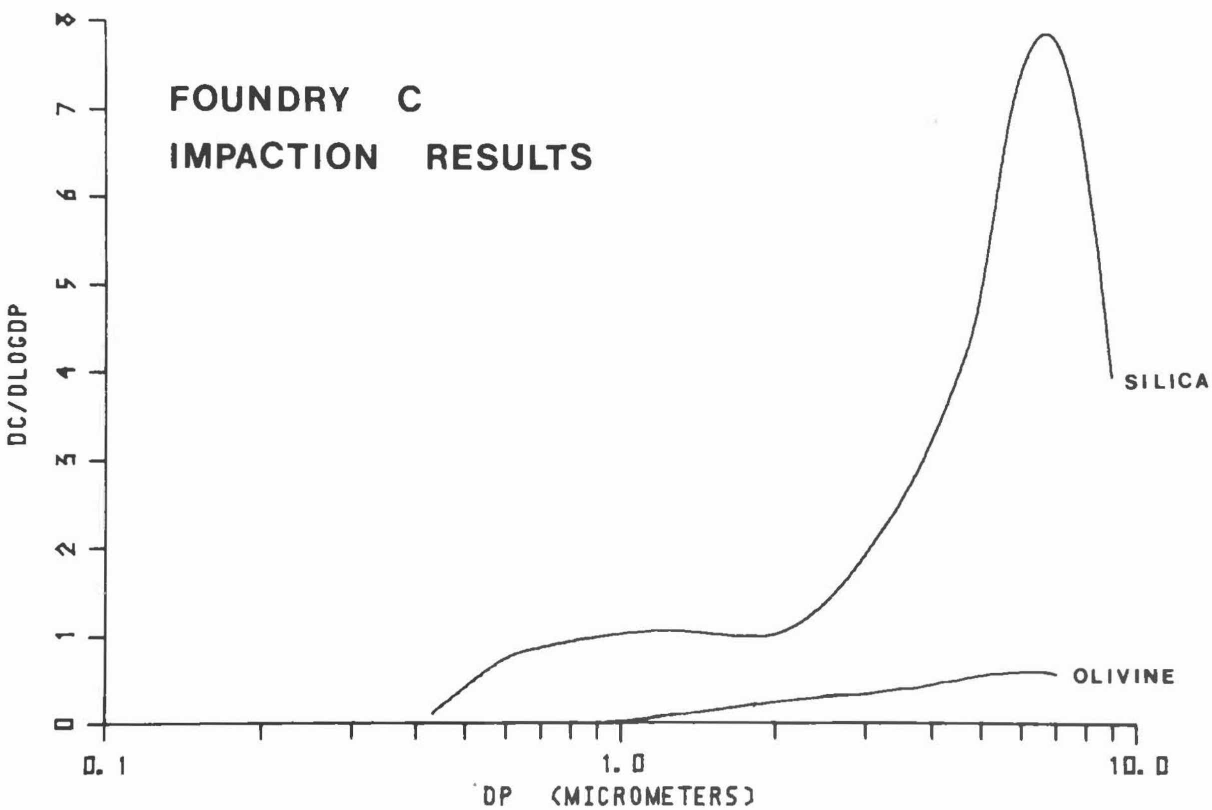

Figure 2b. Impaction results, shakeout area, Foundry C.

This refers to the change in particle concentration divided by the change in particle size. The area under the curve between any two selected particle sizes represents the milligrams per cubic meter in that size fraction.

Note that in both cases the change is quite obvious. For respirable particles in the region <2.0μm there is a reduction of about a factor of two for Foundry A and considerably more than that for Foundry C. In the latter case there were some problems with the exhaust system which undoubtedly contributed to the extremely large variation. The olivine curves for both foundries are remarkably similar in the fine particles region. These two sets suggest that there should be fewer respirable size particles coming from the sand system in a foundry using olivine for molding sand.

SUMMARY AND DISCUSSION OF TAPE SAMPLER RESULTS

Tape samplers have been used for many years to determine the hour by hour variations of total particulate matter in the atmosphere. In the foundries visited in this series of tests, five were used and the samples were taken between 1.5 - 1.8m (5 - 6 ft) above the ground. A sample is drawn through a filter tape at a fixed flowrate for one hour; the tape then automatically indexes to a clean spot and the process repeats. Operating inside a building with a fixed type of dust makes it possible for the spots on the tapes to be compared using a simple optical density meter. Comparisons could be made since each spot had a fixed amount of air drawn through it for the one hour period.

The devices were set up so that a one hour sample was taken each hour - 24 hours a day. The major information that could be determined from such a program was the variations during the day and the daily high and low points. One would expect that the particle concentration would begin at a relatively low point in the morning, build up over the day, and begin to taper off as the activity in the foundry was reduced toward evening. All four foundries were shut down from approximately midnight till 5:00am. Foundry B shut off all power in the building so that there is no overnight data for that foundry.

Figure 3 shows the results for all four foundries in the molding area while silica sand systems were in use. These data were obtained by taking the hour by hour optical density readings for each day during the testing period and averaging them together to get a composite picture of each area where the tape sampler was in use. Foundry A had the typical curve which had been expected. The other three foundries did not drop down to the expected low levels in the night-time hours and, therefore, started the day at a relatively high particle concentration level.

Foundry D, the most automated of the group, had an almost constant level, while Foundry A increased rapidly in the morning and dropped off from lunch time till about 3:00pm. The peak at about 4:00pm was probably due to the initiation of the shakeout procedures.

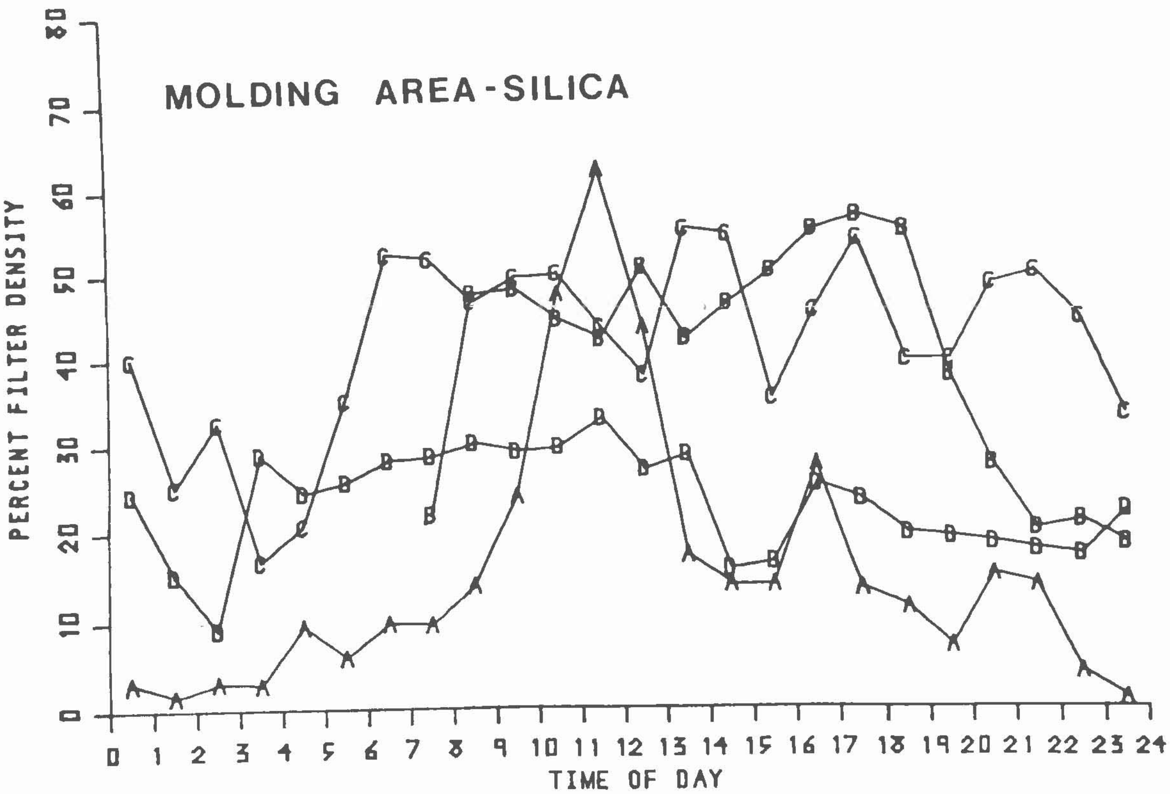

Figure 3. Molding area tape sampler graphs - silica.

Since the physical characteristics of olivine are similar to silica, one would not expect a great change in the measured parameters when the two materials were in use. Olivine is more dense and should settle out faster and perhaps dampen out some of the variations. Figure 4 shows the results for Foundries A and C when the two foundries used an olivine system. There is a rather large overall reduction indicated in the results from Foundry C. Unfortunately, since the ventilation system was not functioning properly when the silica sand system was in use, no definitive statement can be made. On the basis of Figure 4 it should be noted that the combination of ventilation and the use of olivine produced the lowest levels of particulate matter found in any foundry.

At Foundry A, the levels at the beginning and the end of the day are somewhat lower when olivine was in use and the large morning peak has been reduced. However, the levels at mid-morning and mid-afternoon are slightly higher. The reasons for this are not clear.

Only the molding area is discussed here because this is the area where the differences between olivine and silica systems should be most obvious over the 24 hour period. Shakeout, the other critical area, takes place at the two foundries (which used both materials) only at short time periods during the day. The area by area tape sampler results for each of the foundries is found in the complete report (7).

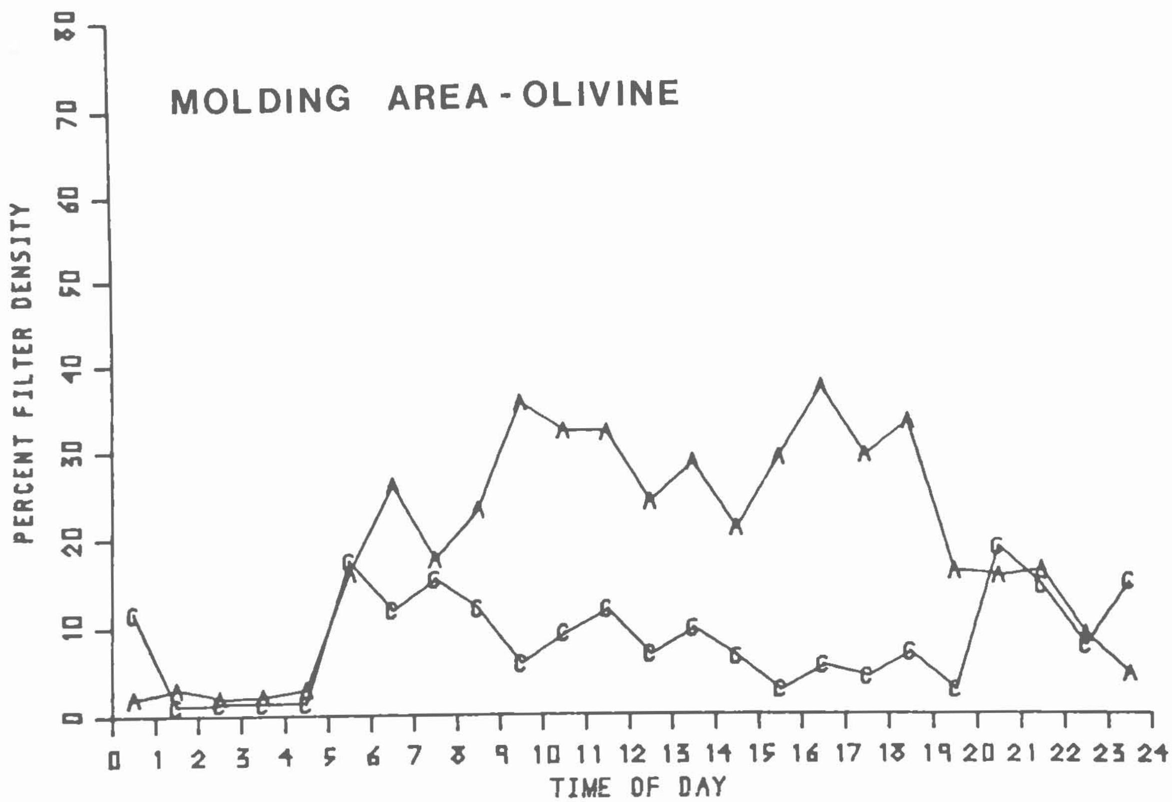

Figure 4. Molding area tape sampler graphs - olivine.

AIR QUALITY EVALUATION AND SUMMARY

In examining the data from these four foundries some generalizations can be made. First, the foundry industry must definitely make an effort to reduce not only the free silica, but also the total dust loadings in the working atmosphere. A second inference from the information gathered is that the use of the mineral olivine, even under a mixed system condition, can reduce the amount of free silica in the foundry atmosphere and reduce the possibility of an occupational health violation. Lastly, it can be stated with assurance that the most effective (and the most expensive) solution is a combination of ventilation and the use of olivine or some other non-free silica based material as the molding material.

The results presented in this study show rather vividly that the atmosphere in operating foundries contains levels of particulate matter which have been declared by regulatory agencies as unsuitable working conditions. Table 3 shows that at the four foundries, while using silica sand, 48% (46 to 95) of all samples taken were in violation of existing regulations. At Foundry D, which had spent a rather large sum of money on a baghouse and an exhaust ventilation system, 15 of 23 samples or 65% were at unacceptable levels.

Results from Foundries A and C indicate that olivine, while not eliminating violations, clearly improved the situation. Impactor results show that the amount of respirable particulate is reduced when olivine is substituted for silica (see Figure 2a and 2b). This coupled with the knowledge that olivine contains less than 1% free silica should convince even the most skeptical that there is a health related advantage in substituting this mineral for silica sand. As stated earlier, experience in the Scandinavian countries supports this contention also. To date all the data available indicate that olivine is less toxic than silica but a definitive health study has yet to be made (4, 5, 6).

Violations were reduced at Foundry A from 29 percent of all samples taken to 11 percent with the only violations occurring in areas where sand type was not a factor. At foundry C the number went from 72 percent of all samples in violation when silica was in use to 5 percent when olivine was the molding material.

Foundry C, when using olivine, was shown to be the cleanest working atmosphere by all the measuring devices used in these tests. It had the fewest violations (1) and the lowest percentage of violations (5%). The ratio of TWA to PEL never exceeded 0.60 in any area of the foundry (Table 4). The respirable particulate as measured by the impactor showed the lowest amount present (Figure 2b) and the particle levels as measured by the tape sampler were lower than any other foundry visited.

The reasons for the above would appear to be related not only to the use of olivine but also to the following factors:

1. The grinding area was separated from the rest of the foundry and was equipped with grinding booths.

2. There was less silica sand in use in this foundry than at Foundry A.

3. More care was taken with housekeeping than at any of the other foundries.

Observations indicate that all foundries would probably show improvements if the last factor, housekeeping, was taken more seriously. This would not bring them into compliance, but would improve the air quality. Periodic cleaning of beams and other ledges where particulate matter tends to collect, more careful use of forklift trucks and loaders, and the isolation of dusty areas from other parts of the plant are just three of the ways in which the situation could be improved.

This study has shown that olivine can improve the air quality in foundries not only by reducing the free silica present but also by reducing the respirable particle matter in the atmosphere. However, it is not the whole answer. Some areas of the foundry, e.g., grinding areas, will have to be equipped with exhaust ventilation and, most probably, isolated from other areas. It is also important to note that exhaust ventilation systems must be carefully designed and tested. The costs are high and the increased energy usage can be substantial. The economics of such decision making are discussed in the complete report but it is difficult, if not impossible, to predict in advance whether ventilation alone is going to bring the particle level in the working atmosphere to acceptable levels (7)..

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QUESTIONS, ANSWERS AND COMMENTARY

Comment (S. Hoenig, University of Arizona):

It's well-known that silica, particularly the one micron size material, has a strong negative charge. Since the earth is also negatively charged you would expect this material to remain suspended in the air, which in fact it does. This has been observed by meteorologists and it's called the electrode effect. It's actually quite well-known.

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*May be obtained from Small Industries Research Office, 312 Willard Building, University Park, PA 16802.

Question (G. Tubich, Tubich and Associates):

Has there been any attempt or work lately on separation of the silica from the olivine based on the differences in specific gravity?

Answer (J. Doninger, IMC Olivine Company):

This is an area of ongoing research, not only in separating olivine from silica sand but also from chromite sand and zircon sand. The results have been mixed - it just isn't that feasible to separate silica sand from olivine. You can do a good job of separating chromite sand from either silica sand or olivine sand. But olivine is about a 3.3 specific gravity while silica sand, I think, is around 2.7 or 2.8.

Question (R. Jacko, Purdue University):

You said Foundry D was a very mechanized foundry and you found relatively high levels of dust. I am curious if you have any personal observations as to why.

Answer (V. Irwin):

Yes, I was at that foundry during the study. As I said, it was very highly mechanized. I have no idea why their dust loadings were so high. They had certainly spent a considerable amount of money on a new baghouse system but conditions were still terrible. You couldn't see for fifty feet in the place when they were operating.

Comment (J. Calhoun, White Consolidated Industries Inc.):

I would like to comment that Foundry D from your data was the most productive foundry by far. It had fewer employees per ton cast and it also had many, many more tons per day than the other foundries. For those two reasons it probably produced a large amount of dust and needed some ventilation work done to capture the dust. If you cast more tons per day, you'll certainly have more tons of dust per day.

Question (J. Calhoun):

What, if any, study was done at Penn State to determine the relative availability of olivine for the foundries that might be interested in using it. In other words, what is the supply and demand situation?

Answer (V. Irwin):

A continuing part of the study has been determining the economic feasibility of using olivine. Such information could be obtained by writing to Penn State University, Small Industries Research Office*. That particular information is just now being published.

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*See footnote, previous page.

Answer (J. Doninger):

George Tubich mentioned yesterday that there are ten million tons of silica sand being consumed and only about five hundred thousand tons of the specialty sands being consumed. Yes, there is more olivine sand available.

Comment (V. Irwin):

I would like to thank the IMC people who gave us some very valuable help in our analysis and provided us with some olivine.

NIOSH

Proceedings of the Symposium on Occupational Health Hazard Control Technology in the Foundry and Secondary Non-Ferrous Smelting Industries

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health

PROCEEDINGS OF THE SYMPOSIUM ON OCCUPATIONAL HEALTH HAZARD CONTROL TECHNOLOGY IN THE FOUNDRY AND SECONDARY NON-FERROUS SMELTING INDUSTRIES

December 10-12, 1979
Chicago, Illinois

Rexnord Inc.
Environmental Research Center
Milwaukee, Wisconsin 53214

Symposium Coordinators:
Robert C. Scholz
La Donna Leazer

Contract No. 210-79-0048

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health
Division of Physical Sciences and Engineering
4676 Columbia Parkway
Cincinnati, Ohio 45226

August 1981

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NIOSH Project Officer: Dennis O'Brien
Project Manager: Robert C. Scholz

DHHS (NIOSH) Publication No. 81-114