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FUGITIVE DUST CONTROL FOR PHOSPHATE FERTILIZER

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FUGITIVE DUST CONTROL FOR PHOSPHATE FERTILIZER

FINAL REPORT

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PERSPECTIVE

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Fugitive dust generated during the normal handling of granular fertilizer products has been a problem for both manufacturers and those selling the fertilizer products. An early commonly used solution for this problem was to coat the fertilizer granules with petroleum oils. This proved highly effective in suppressing dust at the manufacturing and shipping location. This treatment tends to lose its effectiveness if the treated material is stored for long periods after treatment. This loss of effectiveness has been attributed to the fact that the oil used to coat the particles is absorbed into the particles and no longer acts as a surface coating.

To adequately address this problem this project had to first develop a satisfactory method to accurately measure the amount of dust generated. Once this technique was proven, it was possible to rapidly measure the dust generation characteristics of a fertilizer product and determine the effectiveness of the various dust suppression agents available for this purpose.

While the study did not determine how to manufacture granular fertilizers that would not dust, it did evaluate a number of dust suppression agents and conducted plant scale tests to demonstrate the effectiveness of the best coating agents tested. The testing procedure developed can be used to screen new dust suppression agents in a simple and economical manner.

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EXECUTIVE SUMMARY

Dust emissions from handling granular phosphate fertilizer is a significant industrial problem. Because of the diffuse nature of this dust, accurate emission measurement and/or control technique evaluation is very difficult. Research presented in this report addressed the problem of accurate dust emission measurement and dust control technique evaluation.

Industrial process fugitive particle emissions can be defined as particulate matter which escapes from a process flow stream because of material handling, transfer and storage. Because these emissions are not emitted from a stack, they cannot be easily measured using conventional techniques and their impact on air quality is extremely difficult to quantify. Reference methods are available to quantify emissions from ducted sources and reliable emission factor data can be developed for such situations. However no comparable technique exists for the measurement of fugitive dust emissions, Although a number of methods based upon some means of dropping a test sample in an enclosed space have been developed to measure dust release, none provided a totally useful measure of this property.

A simple, reproducible technique to quantify fugitive dust emission potential of a granular product was developed and characterized. This test apparatus consists of a vertical flow dust chamber (VFDC) fitted with a high-volume blower of the type used in the EPA ambient high-volume air sampler. Sampler preparation techniques were developed and operational parameters determined. This test chamber was calibrated and the resulting dust size distribution and concentration measured. The relationship between product properties and product treatment were studied for various granular fertilizer. The measurement technique was found to be sensitive and reproducible and dust emission factors from about 0.0001 to over 0.1 kg/metric ton were measured for various materials. Particle size vs. penetration characteristics of the dust chamber were determined using laboratory generated, monodisperse test aerosols. The chamber effectively size classifies and collects only those dust particles less than about 40 μm aerodynamic diameter, at the normal test chamber operating conditions.

The dust chamber was used as a measurement tool to evaluate the effectiveness of various dust suppressants, applied at various rates on various granular fertilizer products. Fertilizer samples were obtained in quantities of about 100 kilograms. The fertilizer was thoroughly mixed, divided into five kilogram test size samples, and bagged for storage before use or testing. Many types and classes of dust suppressants were tested such as vegetable and petroleum based oils, waxes, petrolatums and emulsions. Materials which were liquid

at ambient temperature were air atomized. Waxes, which are solid at ambient temperature, were sprayed both as water based emulsions and melts. Petrolatum waxes were only sprayed as melts. The quantity of dust suppressant was determined, after application, by weighing. Samples were stored in plastic bags until tested in the dust chamber.

Various batches of fertilizer were characterized by moisture content, size distribution of the granule and crushing strength of the granule. Dust emission test were run on untreated samples and on treated samples after various storage time periods. Fertilizer temperature was found to be a very important variable and was studied in some detail.

Three principal types of fertilizer were used in this dust suppression agent evaluation: granular triple superphosphate (GTSP), diammonium phosphate (DAP) and monoammonium phosphate (MAP). Fertilizer samples were obtained from several different manufacturers for testing.

Various oils including petroleum and vegetable oil blends were evaluated. The kinematic viscosity and oil aniline point were measured and used as indicators for comparison. In summary, most of the oils tested with GTSP show a dust release increase with storage time and only some had good initial dust control capability. With DAP most of the oils tested showed lower dust release and smaller increases in dust emission with storage time.

Waxes evaluated included natural waxes such as Paraffin Wax, Microcrystalline Wax, Candellila Wax, Carnauba Wax, and Montan Wax and many petrolatum and related waxes. The effectiveness of the dust control depends upon the wax application rate. Nominally a 1, 2 and 4 kg/metric ton application rate was used. A most important factor in judging coating agent performance is both the initial and after storage dust control factor. Results show that petrolatum waxes were excellent dust suppressants and that they provide long-term control of fugitive dust emission.

Some of the waxes were difficult to melt and spray so water based emulsions were considered as a means of delivering the wax to the granule surface. As a control, tests were conducted using an equivalent weight of water as the coating agent. In general, the dust release characteristics of fertilizer samples coated with emulsions were similar to those treated with plain water.

Miscellaneous coatings were also tested. Two commercially available Lignin based emulsions, primarily used to suppress road dust, were evaluated. Both coatings performed poorly.

Intermediate Scale Field Tests (ISFT)

Five petrolatum waxes and a wood processing by-product called tall oil were evaluated in the ISFT setup. A small size, portable belt conveyor with a 4 to 12 tons per hour product discharge rate was used. Wax application rates of 1 to 3.5 kg/ton were tested. Of the 5 waxes, 4 had similar performance while the fifth, NW6364LA, appeared to perform significantly better at lower application rates. All tests were conducted using GTSP at ambient temperature.

Full-Scale Field Tests (FSFT)

Based upon the laboratory and intermediate scale tests, a full-scale field test was designed. This test was conducted at the Agrico Chemical Co., Big Bend Terminal in Gibsonton, Florida. This facility handles GTSP at a nominal rate of 250 tons per hour. The coating agent spray system was designed within the facility constraints to provide a maximum spray rate of about 5 gpm. Petrolatum waxes were obtained and used in 55 gallon drum quantities. Although much time and effort was spent on development of an effective spray application system, poor dust control was obtained. After many months of testing it was determined that the high fertilizer temperature was causing the wax to melt and act as an oil. Laboratory studies showed that the elevated fertilizer temperature caused the low-melting temperature wax to lose its performance. A higher melting petrolatum wax was laboratory tested and showed improved performance. The loss in performance was correlated with GTSP granules porosity. At elevated temperature the wax melted and the wax surface coating was absorbed into the granule interior. General criteria for the selection of appropriate dust suppressants were identified.

Selection of a coating agent (dust control agent) must take into consideration process variables such as fertilizer temperature and granulation techniques. Other important factors include melting temperature, viscosity and oil content of the petrolatum wax. From evaluation of other natural waxes it was concluded that shrinkage and ductility of the waxes must also be considered.

The petrolatum waxes were found to be capable of extremely high dust suppression effectiveness at a cost compatible with the oils currently used. They have the added advantage of being more aesthetically pleasing, very clean, easy to spray and odorless. Petrolatum waxes can reduce dust emission by more than 90% and can maintain that performance over a long period of time.

1. INTRODUCTION

Fugitive dust emissions from granular phosphate fertilizer result primarily from handling of the fertilizer during the various stages of manufacture, transfer, storage, shipment and use. Excessive fugitive dust emissions have a detrimental effect on the sale value of the product and can be a major nuisance problem.

Fugitive dust emissions from granular phosphate fertilizer can be caused by a number of factors including:

1. Loss of anti-caking agents due to poor adherence.
2. Incorrect granulation and screening of granular fertilizer.
3. Loss of dust adhered to granule surface and breakage of crystal growths due to impaction and attrition.
4. Breakdown and fracture of granules during material handling operations as at belt conveyor transfer points or load out areas and crushing of granules by material handling equipment such as front end loaders in storage areas.

Fugitive dust can be controlled after generation by conveying the dust, if technically and economically feasible, to appropriate air pollution control equipment. The release of fugitive dust can also be prevented by using dust suppressants. This research is concerned with the latter approach.

An extensive search of existing literature to determine information pertaining to dust suppressants and emission factor measurement methods was conducted. Experimental procedures are described and the various granule characteristics, including size distribution, hardness and moisture content, are discussed.

Laboratory tests were performed to study the performance of a range of dust suppressants and the factors which influence them. Based on the laboratory tests an intermediate scale field test (ISFT) setup was designed and assembled so as to evaluate candidate dust suppressants when used in larger quantities. Results were very comparable with those observed in laboratory tests.

Two petrolatum waxes, YP2A and NW6364LA, both with melting temperatures of about 52°C were used in full scale field tests (FSFT) at a GTSP shipping facility. The performance was not found to be as good as expected from the smaller scale tests. Post field-test experiments conducted in the laboratory showed that a combination of factors including, fertilizer temperature and porosity, wax melting temperature and softening point and coating aging time caused absorption of the surface coating into the granule interior thus leading to a decreased performance level.

General criteria for the selection of appropriate dust suppressants have been developed. Requirements for improved performance in field use are discussed.

2. BACKGROUND

Dust emissions from handling granular phosphate fertilizer are a major problem in the industry. Because of the diffuse nature of the dust emission, accurate measurement and subsequent control are a major problem. Background information relating to this problem is discussed in this chapter.

DEFINITION

Industrial emissions are regulated in order to maintain a certain level of ambient air quality. However, only the ducted industrial emissions have specific regulations and test methods. Other industrial process emissions and natural emissions are grouped into a separate category called fugitive emissions. These fugitive emissions are not specifically regulated though they might have a significant effect on ambient air quality. Fertilizer dust is usually considered a nuisance particulate and when released in a workplace environment the published Threshold Limit Value (TLV) is 10 mg/m^3 (American Conference of Governmental Industrial Hygienists, 1977).

There are many different definitions of the term "fugitive emissions." "Fugitive dust" has been defined as particulate emissions from wind and/or man's activity such as unpaved roads and agricultural operations and "fugitive emissions" are defined as particulate matter generated by industrial activities which escape to the atmosphere from non-ducted sources (Jutze et al., 1977). Industrial process fugitive particulate emissions can also be defined as particulate matter which escapes from a defined process flow stream due to leakage, material handling, inadequate operational control, lack of proper pollution control technique, transfer and storage. Because these emissions are not emitted from a stack, they cannot be measured easily by conventional techniques and their impact on air quality is extremely difficult to quantify.

STANDARDS

During the initial development of ambient air and industrial emission standards, fugitive emissions were believed to be minor and efforts were directed toward control of emissions which could be readily quantified. With the installation of air pollution control devices on ducted stationary sources and the discharge of these emissions at elevations significantly above ground level, the effect of fugitive emissions on ground level concentrations has become more significant.

The Air Quality Act was passed in 1967 and amended in 1970 and the new law was referred to as the 1970 Clean Air Act Amendments. The primary National Ambient Air Quality Standards (NAAQS) for Total Suspended Particulates (TSP) were

75 μg/m^3 - annual geometric mean concentration
260 μg/m^3 - maximum 24 hour concentration not to be exceeded more than once a year

The corresponding secondary standards were 60 μg/m^3 and 150 μg/m^3, respectively, and were described in the Code of Federal Regulations referred to as 40 CFR 50. The primary standards were aimed at the protection of public health while the secondary standards defined levels for the protection of public welfare.

The reference method for the determination of particulate matter (TSP) was based on the use of a high volume air sampler in an enclosure of standard dimensions and was also described in 40 CFR 50. Operational parameters were clearly specified and the upper particle size limit was stated to be 50 μm. A number of studies have been conducted to evaluate the collection characteristics of the air sampler (Wedding et al., 1977; Lundgren and Paulus, 1975; Robson and Foster, 1962) and it has generally been found that particles up to about 60 urn were collected.

As of July 31, 1987, EPA promulgated a new standard based on particulate matter with a carefully defined upper size limit of 10 urn. A new reference method was also proposed. This new standard specifies the mass concentration of particulate matter less than 10 μm (PM-10) and sampled over a 24-hour period. The idea is to concentrate on that portion of the total suspended particulate matter that is likely to be deposited in the thoraic region of the human respiratory tract.

Because PM-10 is only a portion of TSP, the new standard is lower than the old NAAQS for TSP. The annual average and 24-hour average primary standards are 50 μg/m^3 and 150 μg/m^3, respectively. The corresponding secondary standards are the same as the primary standards. Depending on the size distribution of the fugitive dust emissions these lower limits can make the extent of fugitive dust emissions more or less significant.

FUGITIVE DUST EMISSION SOURCES

Fugitive dust emission sources are of both natural and anthropogenic origin. Early work in the study of fugitive dust emissions was stimulated by soil erosion problems due to wind. Important anthropogenic sources, specifically industrial processes, include material transfer and conveying, loading and unloading, storage piles and unpaved areas and roads within industrial facilities.

Material transfer is usually accomplished by means of belt, screw or pneumatic conveyors. A series of conveyors is usually used and the transfer points are the major sources of dust emissions. Emission rates for bulk materials are highly variable and often not known (Jutze et al., 1977). As a result, the effectiveness of control techniques is not quantitatively determined with any great degree of reliability.

Loading and unloading of bulk material from and to storage are other sources of dust emissions. Mechanical agitation, dissipation of kinetic energy on impact and turbulence all lead to generation of dust. Emission factors vary with product type, moisture content and various process parameters. Some quantitative data is available but is of questionable reliability (Jutze et al., 1977).

Large tonnages of bulk materials are often stored in open or partially enclosed storage piles and storage may be for a short time with high turnover or for a long time to meet cyclical demand. Storage pile operations leading to dust emissions include loading onto piles, vehicular traffic, wind erosion and loadout from piles. The relative importance of each of these operations depends on factors like storage pile activity, pile configuration, method of loading and unloading, wind speed and precipitation. Emission factors (U.S. Environmental Protection Agency, 1976) and various equations (Jutze et al., 1977; Midwest Research Institute, 1977; Carnes and Drehmel, 1981) have been developed, but they are of limited value for general use.

Roads on plant property can be another major source. Vehicular traffic causes increased mechanical breakdown of material and suspends particulate matter in the air. The emission factor for roads has been found to be a function of silt content, vehicle speed and weight and a number of equations have been developed (Jutze et al., 1977; Midwest Research Institute, 1977; PEDCO Environmental, Inc., 1976).

FUGITIVE DUST MEASUREMENT METHODS

As discussed earlier, reference methods are available to quantify emissions of particulate matter from ducted sources and so reliable emission factor data can be developed for such situations. However, no such single technique exists for the measurement of fugitive dust emissions. Existing methods can be divided into field scale and laboratory methods. The field scale methods were aimed at developing emission factors on the basis of large-scale tests of full scale material handling operations.

The six most widely used field scale methods are

1. Upwind/Downwind sampling
2. Roof Monitor sampling
3. Quasi-stack sampling
4. Exposure profiling
5. Wind tunnel method

6. Tracer method

Upwind/Downwind sampling (Kolnsberg, 1976) involves the measurement of particulate matter concentration in the atmosphere upwind and downwind of the source. Meteorological parameters are also simultaneously measured. Based on the concentration map obtained and the values of the meteorological parameters, Gaussian dispersion equations are used to back-calculate the source emission rate.

Roof monitor sampling (Kenson and Bartlett, 1976) involves sampling at building openings and has been used with indoor sources. Emission rates are calculated based on the measured concentration and the exhaust flow rate through the opening. No meteorological data is needed. Quasi-stack sampling (Kolnsberg et al., 1976) requires temporarily enclosing the source and drawing off the emissions through ductwork and measuring particulate matter concentrations using standard stack sampling methods. Exposure profiling (Cowherd et al., 1974) is a multi-point sampling technique where particulate matter concentrations downwind of the source are isokinetically determined across the plume cross-section. Emission rate is then calculated by a mass balance approach. In the wind tunnel method (Cuscino et al., 1983) dust generated by wind blowing over an exposed surface is measured. A wind tunnel with an open-floored test section is placed over the surface to be tested and air is drawn at controlled velocities. Isokinetic samples are collected and used to calculate dust concentrations. Finally, the tracer method (Hesketh and Cross, 1983) consists of releasing a tracer at the dust source. Downwind from the dust source both dust and tracer concentrations are determined and based on this ratio and the quantity of tracer released the dust emission rate is determined.

The field scale techniques described above were all developed and applied to special situations and were often dependant on meteorology. The techniques are all complicated, time consuming and expensive. Because of the scale of the tests, the performance of dust suppression techniques cannot be easily and quickly determined. In addition, reproducibility is a major problem.

A number of smaller scale techniques for use in the laboratory have also been developed. A dedusting tower (Hoffmeister, 1979) consisting of a 8.6 cm diameter glass tube fitted with seven screen stages has been used. Air is sampled such that air flow is countercurrent to a falling 250 ml sample at a velocity of 0.9 m/sec. Weight loss of the test sample is used to calculate dust emission factor. Another laboratory scale technique involves the use of a spouted bed arrangement (Kjohl, 1976) where 1.2 liters of sample are used in the spouted bed and the dusty air is sampled through a filter bag. Test conditions are such that particles up to 200 um are sampled. An analogous technique is one where a fluidized bed of 400 grams of material, 10% test sample and 90 % sand, is used and the dust generated is sampled with a cascade impactor (Schofield et al., 1979). All these techniques are more representative of pneumatic type conveying systems. The fluidized bed technique has been compared with a rotary drum technique and an impact type test (Higman et al., 1983). The impact type test involves dropping 300 grams of material into a box and exhausting the box through a cascade impactor (Wells and Alexander, 1978). All the above tests were more suited to powders and reproducibilty has been stated to be 15 % to 20 %. The small sample sizes lead to greater variabilities in dust measurement. In addition, for moderately dusty materials, the small amount of dust generated would require more accurate gravimetric analysis. None of the above techniques really simulate dust generation at transfer points.

A semi-field scale technique where 50 kg of coal was discharged from a hopper in three minutes through a series of belt conveyors onto a stockpile (Nakai et al., 1986) is more directly based on an impact type dust generation process, as at transfer points. Dust concentrations at a transfer point were measured with an optical device and efforts were made to correlate emission factors with ambient dust concentrations.

A number of methods based on some means of dropping a test sample in an enclosed space have been developed. A technique called the powder spill test column (Cooper and Horowitz, 1986) uses 10 gram samples which are dropped a distance of 1 m inside a 17 cm diameter column and the air is exhausted through a 47 mm filter at a flow rate of 52 liters/min. A particle size limit of 40 µm is stated. Another technique used to evaluate spills and pressurized releases (Sutter et al., 1982; Sutter and Halverson, 1984) was based on a chamber 2.9 m in diameter and 3 m high where small quantities of the sample were discharged and the air was sampled with high volume air samplers. The ASTM method for determining an index of dustiness of coal (American Society for Testing Materials, 1975) consists of a 1.5 m tall metal cabinet with a 0.46 m square cross-section. A minimum of 23 kg of the sample is placed on a tray within the cabinet and released at a 1.2 m height. After 5 seconds two slides are inserted 0.6 m below the release point and pulled out 2 minutes and 10 minutes afterwards. The dust settled on the slides is gravimetrically analyzed and reproducibility of 20 % is claimed. Another technique used with coal uses a belt conveyor to discharge coal samples into a 0.46 m diameter chamber of variable height (Cheng, 1973). The chamber is evacuated with a high volume air sampler and dust is sampled with a cascade impactor. A variation of the chamber technique called the Totman dust test device uses a 0.9 m tall chamber of 0.15 m x 0.2 m cross-section with a chevron type internal material flow arrangement. Because of this arrangement, unlike other chamber techniques where only one impact is used, at least 4 impacts occur before the product comes to rest. The air is sampled in a counter-current manner through a filter for gravimetric analysis. A review of these and other laboratory techniques has been published elsewhere (Hammond et al., 1985).

DUST SUPPRESSANTS

Coating agents have been applied to a very large number of materials to suit many requirements which include moisture control, prevention of caking, providing slow release capability and reducing dustiness. The most commonly used dust suppressant is water. When coal moisture content was raised from 0.8 % to 1.5 % and mixed briefly in a tumbler, the emission factor was reduced 70 % (Cheng, 1973) though excessive mixing created more dust due to breakage. This same effect has been reported with different kinds of coal (Nakai et al., 1986) and has been reported to cause agglomeration of coal dust. A number of studies have also documented the increased adhesive forces between particles and surfaces with increased relative humidity due to formation of liquid bridges (Stone, 1930; Van Den Tempel, 1972; Larsen, 1958; Corn, 1961; Ketkar and Keller, 1975; Corn and Stein, 1965). However, excessive moisture content with phosphate fertilizer can cause caking problems (Hoffmeister, 1979; Kjohl, 1976) and decrease granule crushing strength (Kjohl, 1976), thus leading to increased dustiness due to granule fracture and subsequent generation of fines.

The most common dust suppressant used in the fertilizer industry is oil. Oils with high viscosities are suggested to avoid the problem of absorption into granules and consequent loss of effectiveness (Hoffmeister, 1979). Oils with high paraffinic content are also suggested as effective dust suppressants for fertilizer (Frick, 1977). Extensive work is reported in patent literature on the use of coating agents to increase granule strength, reduce caking tendency, reduce dustiness and control moisture content. A list of patents is presented in the Appendix. Coating agents used have included amines, mineral oils, surfactants, fillers, acids, waxes and many other materials. These patents and some others are reviewed elsewhere (Sarbaev and Lavkovskaya, 1978).

In the laboratory, dust suppressants have been applied in a rotary drum where the granules and coating agent are both introduced (Hoffmeister, 1979). In actual industrial facilities coating agents used are primarily petroleum oil blends and have been sprayed in screw conveyors, mixers, on belt conveyors, coolers and material transfer points and sufficient mixing occurs so as to effectively distribute the coating agent (Achorn and Balay, 1974).

3. EXPERIMENTAL PROCEDURES

Extensive experimental work was carried out in order to establish the nature and extent of the fugitive dust problem associated with handling phosphate fertilizer. The apparatus and procedures used are described in this chapter.

LABORATORY TESTS

Sample Preparation

A supply of uncoated granular phosphate fertilizer was a prerequisite to any experimental work. Samples of fertilizer were obtained in quantities of at least 100 kilograms and stored in 19 liter (5 gallon) plastic buckets with tight fitting lids. The sample buckets were kept air tight during transfer from the field to the laboratory. Fertilizer sampling locations were chosen with care and included belt conveyors, material transfer hoppers and storage piles.

A batch of uncoated fertilizer consisting of about 80 kilograms of product was poured out of the buckets on to a clean plastic sheet laid out on the floor, The pile of fertilizer was thoroughly mixed to ensure that all parts of the pile were homogeneous. Five kilogram test samples were then made by collecting 8 to 10 scoops of product from various parts of the pile and stored in polythene bags to provide a stable environment for the sample. This technique was also used when making test samples of coated fertilizer.

Five kilograms was chosen as the standard test sample size. This sample size was considered to be large enough to overcome the possible variabilities in the fertilizer and more representative of the average characteristics of the bulk material. This sample size was also the maximum quantity that could be conveniently handled without spillage during experiments. In addition, the larger the test sample size the greater the amount of dust generated and, hence, the greater the accuracy of gravimetric analysis of the emitted dust.

Application of Dust Suppresants

In actual plant situations the dust suppressant is usually applied on the fertilizer when it moves past a spray header on a belt conveyor or at a product transfer point. The dust suppressant is applied as a spray produced either by a high pressure airless spray system or by a lower pressure air atomized spray system.

The dust suppressants tested have included vegetable and petroleum based oils, waxes, petrolatums, emulsions and many other materials. Dust suppressants which were liquid at ambient temperatures, were dispersed using an air atomized spray system at a pressure of about 138 kPa (20 psig). A Sears Model 919.156580 portable air compressor was used with a Sears Model 919.156140 spray nozzle for this purpose. This system was used because of its similarity to actual industrial practice, ease of use and availability. This system was designed for use with dust suppressants which did not require special handling and whose viscosities at ambient temperature were such that they could be sprayed directly.

However, waxes, which are solid at ambient temperatures, were sprayed either in the form of water based emulsions or melts. Some natural waxes were easily emulsified by a process of saponification. These waxes were tested in both forms, where possible. Emulsification of petrolatum waxes required a more complicated process using special emulsifiers and they were, therefore, sprayed only as melts.

The wax emulsions were sprayed without further treatment. The non-emulsified waxes, on the other hand, were first melted by putting them in a plastic container immersed in boiling water. Once heated to a temperature of about 75°C the liquid wax was sprayed using an air atomized nozzle (Spraying Systems #SU-1) in a siphon arrangement. To prevent plugging problems due to solidification of wax, the nozzle was heated to an appropriately elevated temperature by using a heating tape and variable transformer arrangement.

The test sample to be coated was retained in the storage bag for the coating operation. The exposed surface layer was first sprayed lightly, then a new layer was created by mixing the bag contents and this new layer was sprayed. This process was carried out till the required amount of dust suppressant was added. The quantity of dust suppressant added was determined by weighing the test sample before and after application of the dust suppressant by using a single pan balance with a 20 kg capacity. Once the coating operation was complete the coated sample was stored in the polythene bag pending the drop test.

Measurement of Some Fertilizer Properties

Moisture Content. For the purposes of characterization of various batches of fertilizer, moisture content was determined for at least two test samples per batch of fertilizer. The technique used was that recommended by the Association of Florida Phosphate Chemists (Association of Florida Phosphate Chemists, 1980).

Three 2-gram samples were taken from each test sample to be evaluated and placed in a vacuum oven (Precision Model #19). The samples were subjected to a temperature of 50°C and a vacuum of 508 mm of mercury for 2 hours with a stream of dry air being circulated in the oven. The weight loss of each of the three samples was determined with an electronic single pan balance (Mettler Model #HK60) and converted to a "percent moisture content" representation. The average value for the three samples was calculated and used as a measure of the moisture content of the test sample.

Size Distribution. Size distribution of the granular fertilizer was another parameter of interest. A sieving machine (Gilson Model #SS-15 Sieve Tester) with a set of 6 sieves was used. The sieves used were U.S. Standard 6, 8, 12, 16, 20 and 40 mesh. One-hundred-gram samples were weighed out using an electronic single pan balance (Sartorius Model #2355) and then poured into the first sieve. The sieving machine was operated for 10 minutes. At the end of the sieving cycle the size fractionated sample was collected in preweighed petri dishes and re-weighed. The weights of the various size fractions were then used to calculate the size distribution.

Crushing Strength. Crushing strength of a granule is a measure of the resistance to fracture. The technique used is also known as the TVA method. (Hoffmeister, 1979). Size fractionated samples were prepared with the sieving machine as described earlier. For a particular size range a number of granules were placed on a single pan spring balance with a weighing range of 0 to 10 kilograms. A load was applied on individual granules by pressing down on the granules with a steel rod. The scale reading at the point of granule fracture was noted and the average value for a number of granules was calculated. This procedure was carried out for the various size fractions to establish the crushing strength distribution.

Emission Factor Measurement

Apparatus and Operating Procedure. Emission factors for coated and uncoated fertilizer were measured by means of a "drop test" using a vertical flow dust chamber (VFDC). The VFDC was an enclosure constructed of 1.3 cm (1/2 inch) thick plywood (Figure 1). The enclosure was 0.6 m (2 feet) square and 0.9 m (3 feet) high. The top of the enclosure had two openings: a 0.2 m (8 inch) diameter opening into which a 0.6 m (2 foot) long duct was mounted and a 18 cm (7 inch) by 23 cm (9 inch) rectangular opening over which a high volume air sampler (General Metal Works Model #2000) was placed. A baffle separated the two openings in terms of the air flow characteristics of the enclosure (Figure 2(a)). The test sample was introduced manually through the 0.2 m diameter feed tube and fell 1.5 m before striking the floor. Dust was released during the pouring process and also when the sample struck the floor, due to the combined action of impaction and attrition. The released dust was picked up by the high volume air sampler and deposited on a filter for gravimetric analysis.

About 10 % of the samples in a batch of fertilizer were tested in an uncoated state to establish an emission factor in units of g/kg for untreated fertilizer for that particular batch. The remaining samples were treated with the dust suppressants to be evaluated and then tested.

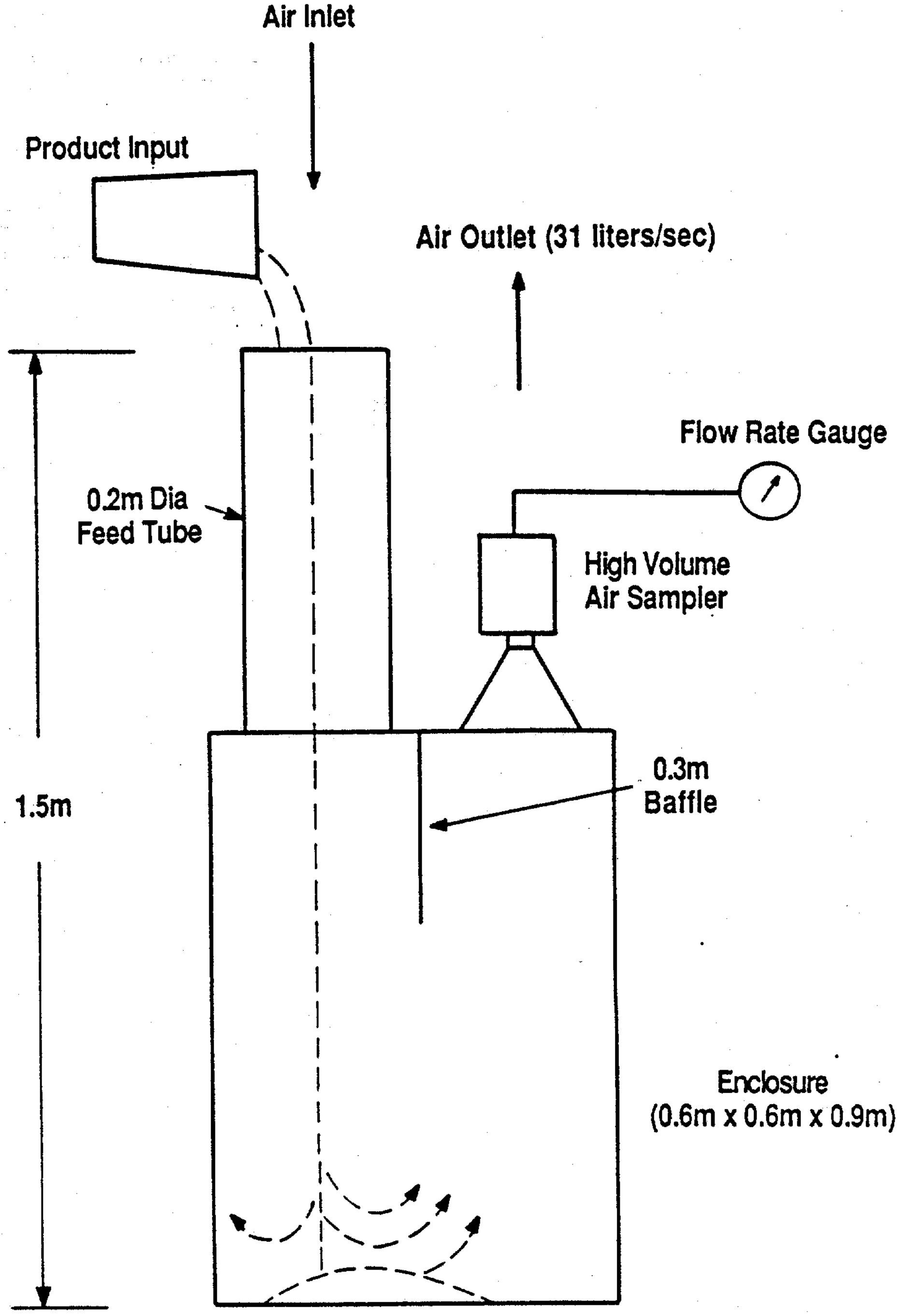
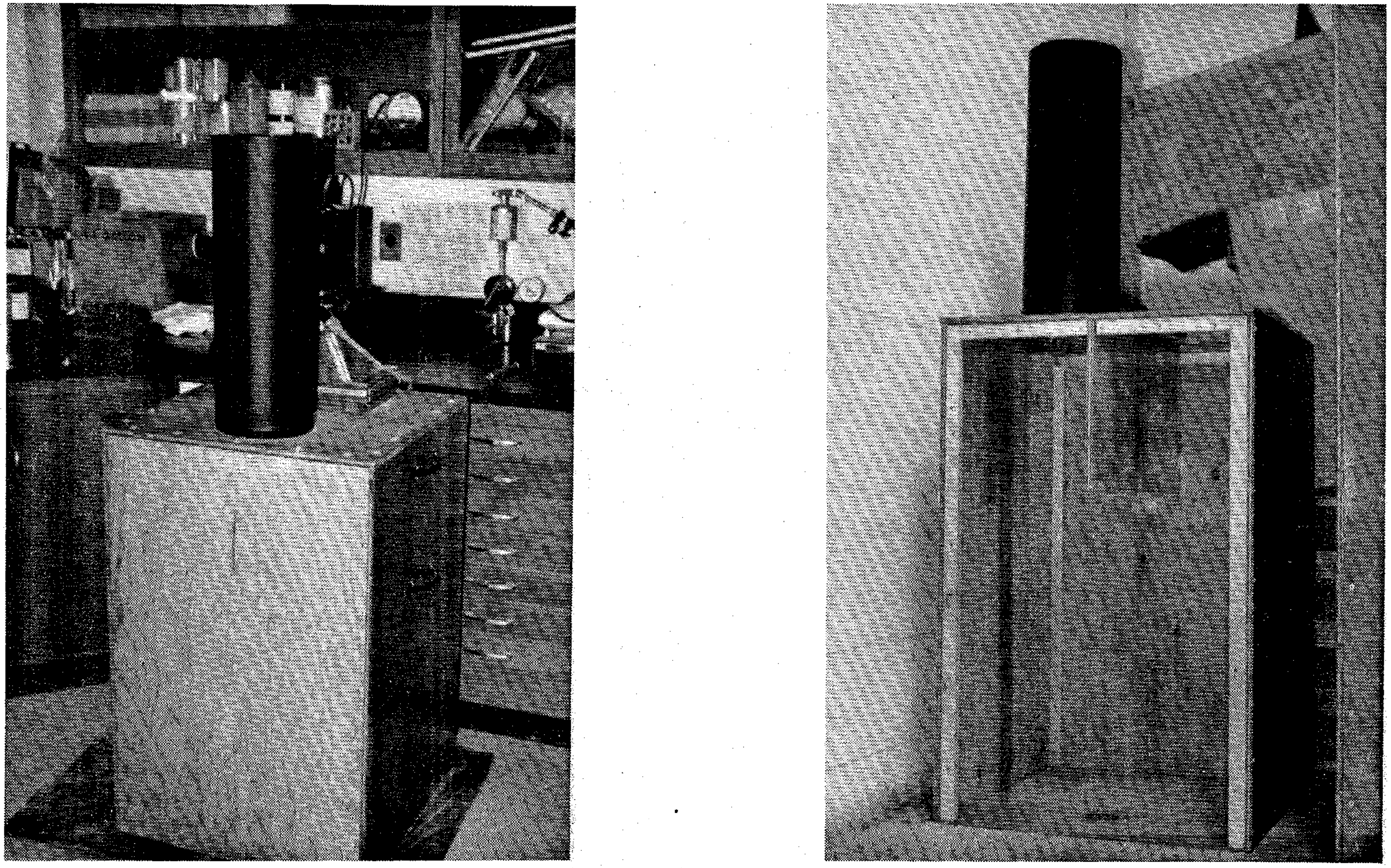


Figure 1. Vertical flow dust chamber.



(a) (b)

Figure 2. Photographs of the vertical flow dust chamber. (a) the test setup (b) the enclosure.

The test sample was first preweighed to the nearest gram with a 20 kg capacity single pan balance and then transferred from the plastic storage bag to a pouring bucket. Four 20 cm x 25 cm (8 inch x 10 inch) glass fiber filters were weighed using a single pan balance (Mettler Model #H6) equipped with a special attachment for weighing filters. The VFDC was placed on a plastic sheet spread out on the floor. The first filter was mounted on the high volume air sampler which was then placed over the enclosure opening as shown in Figure 2(b). The high volume air sampler was previously calibrated by using a set of calibration orifices to develop a correlation between air flow rate and sampler pressure drop as measured by a magnahelic gage (Figure 3).

The air sampler was turned on and set to operate at a flow rate of 31 liters/sec, unless, specifically stated otherwise. The sampler flow rate was adjusted with a variable transformer. After 15 seconds the test sample was steadily poured into the enclosure through the feed tube in a pouring time of 60 seconds. After an additional 45 seconds of operation the air sampler was switched off. Thus, the total run time of the sampler was 2 minutes and this was equivalent to a total of about 10 air changes in the enclosure, 5 of which were during material transfer.

After the first drop of the test sample the "dirty" filter was removed from the air sampler and the test sample, now on the plastic sheet on the floor under the enclosure, was transferred back into the pouring bucket. The above procedure was repeated 3 more times. The weight gain of the 4 filters was determined and normalized to given an emission factor in units of grams of dust per kilogram of test sample. The average value of the emission factors calculated for the four filters was determined and represented the average emission factor for the test sample. This procedures was used to determine emission factors for uncoated and coated test samples. A measure of performance of a coating agent or dust suppressant was the dust release and was defined as the ratio of the coated emission factor to the uncoated emission factor and expressed as a percentage.

Discussion. The VFDC configuration and test procedure described were established after an extensive evaluation of a number of parameters. These included baffles, feed tube diameter, enclosure height, air flow rate and material pour rate.

The baffle in the VFDC was introduced in the basic design to better define the air flow in the enclosure and to prevent possible "short circuiting" of the air flows at the enclosure inlet and outlet. Tests with granular triple superphosphate (GTSP) showed that the presence of the baffle did have a small, but not negligible, effect on measured emissions. The principal value of the baffle, however, was that it permitted a clearer mathematical description of the air flow in the enclosure. Dust emission factors for test samples were measured using a "drop test" procedure as described earlier. Four drops were performed per test sample in a "drop test" as a matter of practice. This

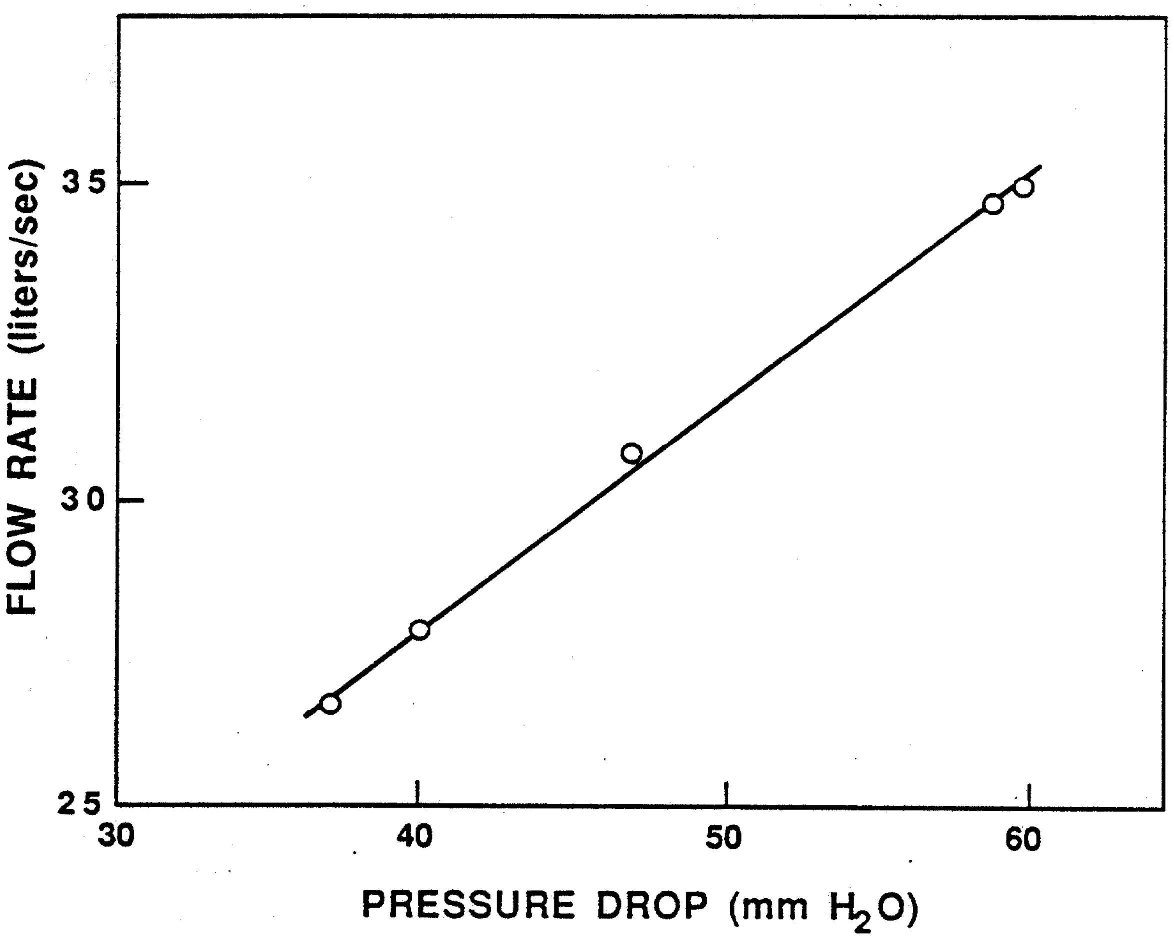


Figure 3. Calibration for the high volume air sampler.

was done in order to obtain an average value for the dust emission factor. A single drop would usually, but not always, represent a maximum emission from the test sample and would not be representative of an average emission resulting from a series of handlings of that same test sample. Four drops would thus permit a more representative estimate of dust potential of a test sample, especially when comparing different materials.

The effect of various feed tube diameters was also evaluated. As shown in Table 1 the diameter of the feed tube affects the velocity of the air at the inlet and so measured dust emission factors were higher for the smaller diameter feed tube. However, both the 0.15 m and 0.25 m diameter feed tubes were found to be not quite convenient for regular operational use. Therefore, a 0.20 m diameter feed tube size was used as standard. The 0.6 m length was chosen because this would make the effective height of fertilizer discharge from the pouring bucket, 1.5 m from the ground. A height greater than this would have made the process of fertilizer discharge, which was manual, very inconvenient.

Enclosure heights of 0.9 m and 1.5 m were considered next. The effective fertilizer discharge height was 1.5 m for both configurations. The configuration with the 0.9 m enclosure was as shown in Figure 1 while the configuration with the 1.5 m enclosure height had the feed tube projecting into the enclosure rather than out of it. Results of tests conducted with phosphate rock and white sand (Table 2) show that the measured dust emissions were consistently higher with the 0.9 m enclosure, probably because of a smaller volume of dead space and a shorter distance between the point of dust emission and the air sampler. The difference in measured emission factor was of the order of 10% and so this factor did not play a major part in the eventual selection of an enclosure height. The 0.9 m enclosure was selected as standard because it was much easier to move around due to its lower weight and smaller dimensions.

Using the standard inlet size and enclosure height, the effect of three different air flow rates was evaluated. The air flow rate was varied by changing the applied voltage to the air sampler. The maximum possible air flow rate was found to be about 35 liters/sec and, as shown in Figure 4, operating the sampler at this condition did not result in a significant increase in measured dust emission. A flow rate of 31 liters/sec was chosen as an optimum value for emission factor measurement tests. It was observed that a flow rate of 21 liters/sec resulted in emission factor measurements which were 21 % lower than that at 29 liters/sec and that the air flow rate had a nonlinear effect on measured dust emission factor. If the air sampler was operated at a flow rate of 26 liters/sec instead of the optimum 31 liters/sec, the deviation in the measured dust emission factor would be less than 10 %.

TABLE 1

Effect of Feed Tube Diameter on the Emission Factor of GTSP Samples

Sample I.D.	Drop Number	Flow Rate (liters/sec)	Emission Factor (g/kg)	Average (g/kg)	Feed Tube Diameter (m)
A	1	32	0.0248	0.0225 (gsd=0.0017)	0.15
	2	32	0.0234		
	3	32	0.0211		
	4	32	0.0208		
B	1	33	0.0167	0.0162 (gsd=0.0005)	0.25
	2	33	0.0154		
	3	33	0.0166		
	4	33	0.0162		

NOTE: "gsd" is the Geometric Standard Deviation.

TABLE 2

Effect of Enclosure Height on the Emission Factor of Phosphate Rock and White Sand Samples

Product Type	Sample I.D.	Enclosure Height (m)	Average Emission Factor (g/kg)	Overall Average (g/kg)
Phosphate Rock	A	0.90	0.1361	0.1362
	B	0.90	0.1363	
Phosphate Rock	C	1.50	0.1214	0.1206
	D	1.50	0.1198	
White Sand	A	0.90	0.0142	0.0133
	B	0.90	0.0123	
White Sand	C	1.50	0.0118	0.0117
	D	1.50	0.0115	

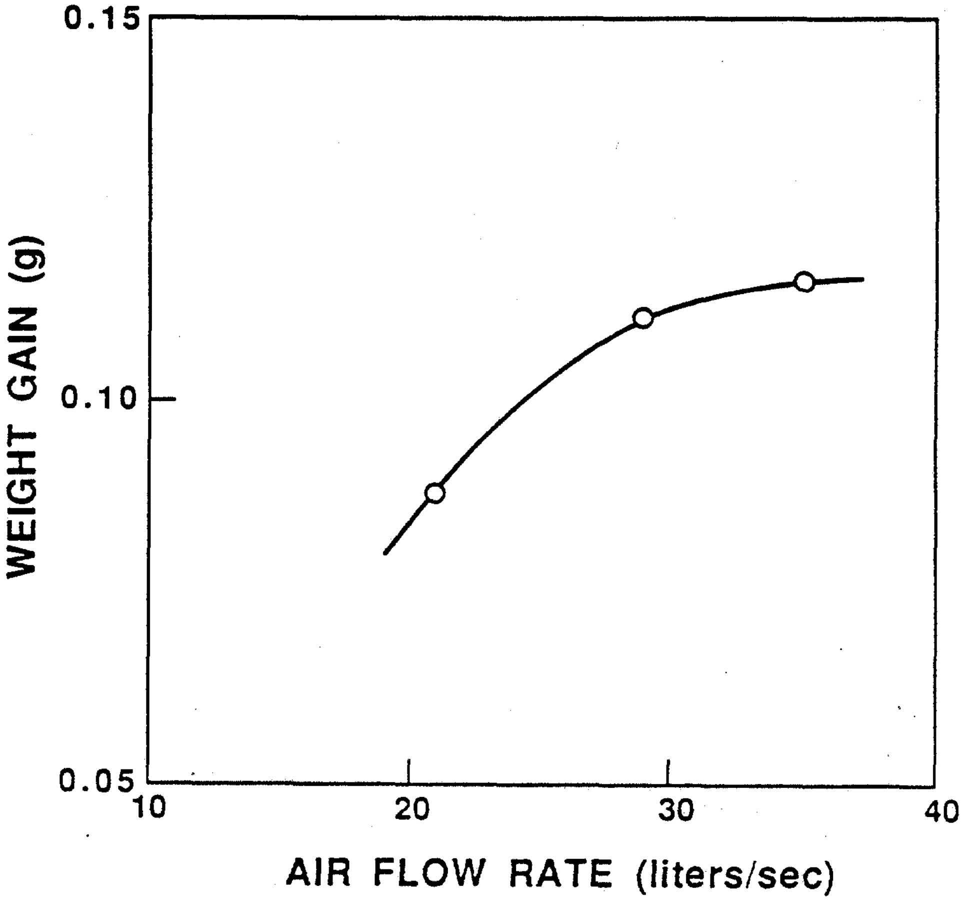


Figure 4. Effect of air flow rate on the measured dust emission of GTSP samples.

TABLE 3

Effect of Pour Time on the Emission Factor of GTSP Samples

Sample I.D.	Drop Number	Pour Time (seconds)	Emission Factor (g/kg)	Average (g/kg)
A	1	30	0.0448	0.0343 (gsd=0.0089)
	2	30	0.0383	
	3	30	0.0260	
	4	30	0.0279	
B	1	60	0.0362	0.0366 (gsd=0.0122)
	2	60	0.0536	
	3	60	0.0256	
	4	60	0.0308	
C	1	90	0.0312	0.0330 (gsd=0.0111)
	2	90	0.0491	
	3	90	0.0265	
	4	90	0.0250	

NOTE: Enclosure height = 1.50 m (5 feet).
Air flow rate = 25 liters/sec (60 cfm).
"gsd" is the Geometric Standard Deviation.

Material pour rate was varied by pouring 5 kilogram test samples of GTSP in three different pour times, viz., 30, 60 and 90 seconds. As shown in Table 3, for the pour times evaluated, the variations in measured dust emission factor as determined by the "drop test" were not extreme for moderately dusty materials like GTSP. For operational reasons, the 60-second pour time was found -to be most convenient and was thus established as the standard pour time. Tests conducted with phosphate rock, a significantly dustier material, showed that pour rate did have a more significant impact (Figure 5) though the measured emission factor was that from a single drop. However, the 60-second pour time is still a valid selection since relative dust emission factor is the primary parameter of interest.

The cross-sectional area and air flow rate were selected so that the particle collection characteristics of the VFDC would be similar to that observed with the high volume air sampler operating in a standard housing as used for ambient air sampling. The VFDC test procedure simulates the process of dust generation due to handling of bulk materials as at transfer points in material conveyors and unloading stations.

Both VFDC configurations were calibrated with monodisperse ammonium fluorescein aerosols and glass beads. The monodisperse ammonium fluorescein aerosols were generated with a vibrating orifice aerosol generator (TSI Model #3050) while the monodisperse glass beads, purchased commercially, were dispersed from a flask by compressed air. The fractional penetration of particles of various sizes was determined gravimetrically for glass beads and fluorimetrically for ammonium fluorescein aerosols. With the air sampler operated at 26 liters/sec the particle penetration characteristics of the two units were found to be almost identical (Figure 6). The measured 50 % cut point for both units, when operated in an identical manner, was found to be 40 µm.

In summary, the standard VFDC configuration used was like that shown in Figure 1. Five kilogram test samples were standard as was a 60 second pour time, a 2 minute air sampling duration and an air flow rate of 31 liters/sec.

Dust Size Distribution Measurement

The size distribution of dust emitted due to handling of various materials was measured using single stage impactors like that shown in Figure 7. For a given flow rate the 50% cut size can be changed by changing the flow area in the impactor or, correspondingly, by using separate single stage impactors with different nozzle widths. Three impactors with 50% cut sizes of 42 µm, 25 µm and 13.6 µm when operated at 30 liters/sec were used. The calibration of the single stage impactors has been described elsewhere (Vanderpool, 1983).

The impaction surface was prepared by lining it with aluminum foil cut to size and then coated with a silicone spray and weighed.

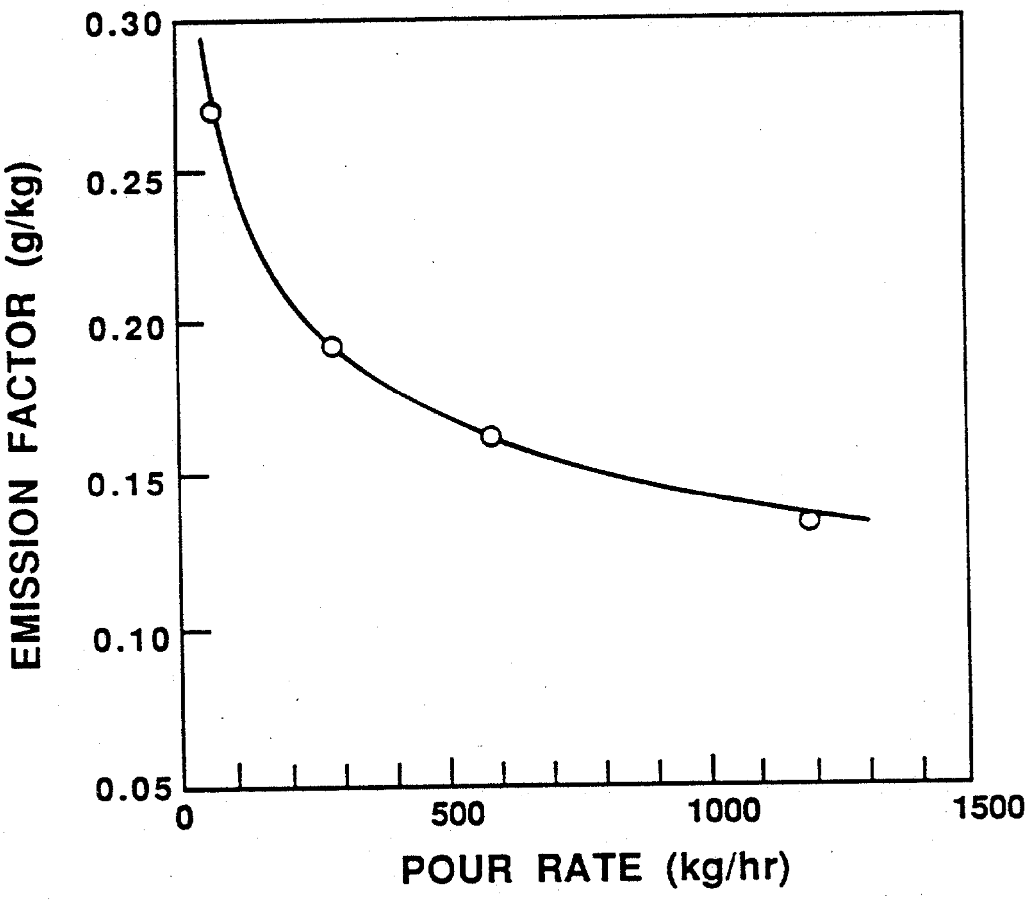


Figure 5. Effect of pour rate on the measured factor of phosphate rock samples.

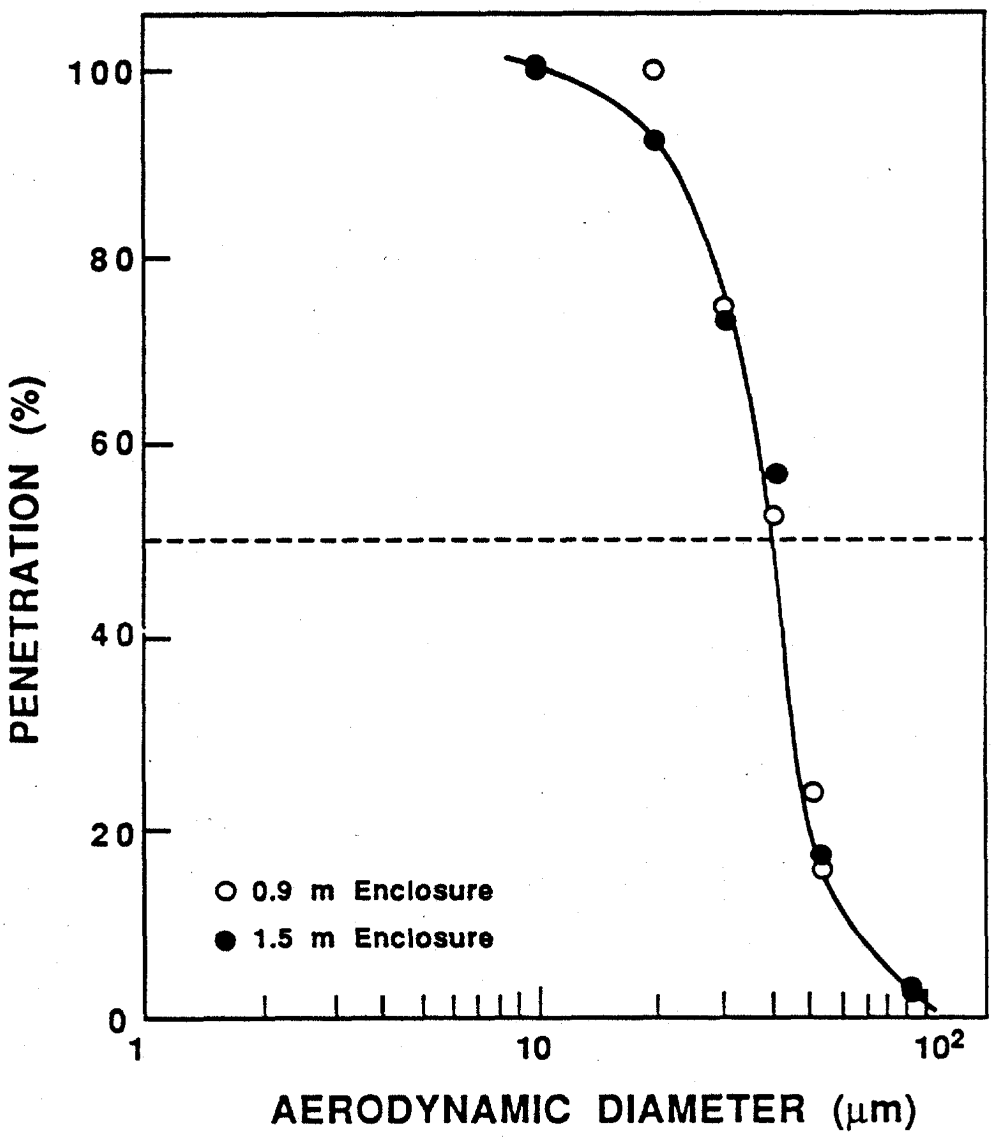


Figure 6. Calibration for two configurations of the vertical flow dust chamber.

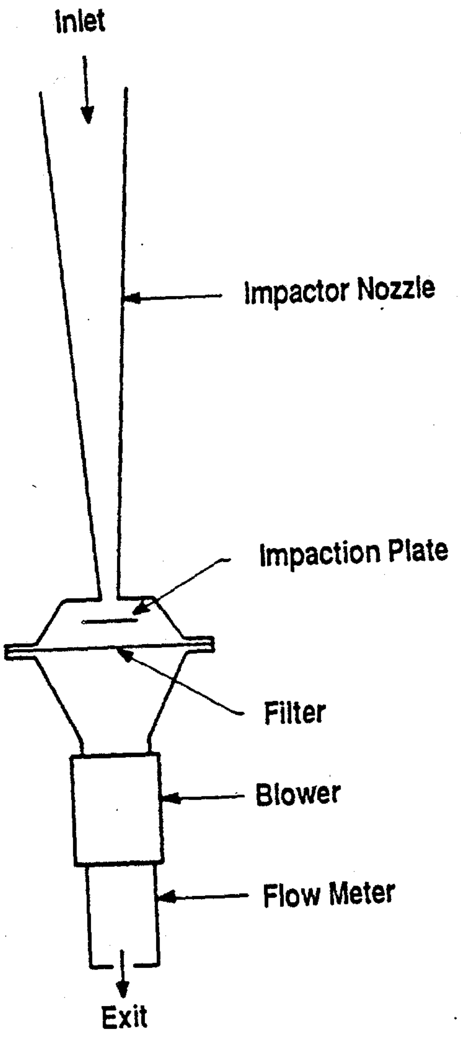


Figure 7. Schematic of a single stage impactor.

The first impaction surface was mounted in the nozzle section of the 42 μm impactor. Four spacers were placed on the rear side of the impaction surface and the first pre-weighed filter was laid over it. The high volume air sampler was then mounted on the impactor and bolted in place. The impactor-high volume air sampler assembly was then placed over the enclosure opening. The procedure was then similar to that for the first drop of the "drop test" for emission factor measurement. For each test a new sample was used. At the end of the first drop the impaction surface and filter were carefully removed. Prior to the next drop of the test sample the second impactor nozzle was set up and a similar assembly and test procedure followed. After the third drop test with the third impactor nozzle the weight fractions on the impaction surface and filter were determined and the size distribution calculated.

INTERMEDIATE SCALE FIELD TESTS

Apparatus and Operating Procedure

From extensive laboratory experiments it was apparent that full scale field tests to demonstrate the validity of laboratory results would be much more likely to succeed if intermediate scale tests were first performed. The intermediate scale field tests were designed to evaluate possible scale-up problems and to determine the influence of various operating conditions.

An intermediate scale field test (ISFT) setup was designed to handle a minimum of about 70 kilograms of fertilizer at a maximum feed rate of about 10 tons per hour. The setup was composed of two major components which included the fertilizer handling system and the coating agent spray system.

The fertilizer handling system consisted of feed and discharge hoppers and a belt conveyor. The system was made portable by mounting the conveyor and feed hopper on a modified boat trailer. The boat trailer was a Harding Model #B-16-7 unit with an overall length of about 5.2 m and a 320 kilogram load capacity. The conveyor and feed hopper support structure was made of 5 cm x 10 cm (2 inch x 4 inch) pressure treated wood and was attached to the boat trailer frame with "U" clamps. The trailer was equipped with a seven foot long tounge which was removed once the setup was put in place.

A general drawing of the fertilizer handling system is shown in Figure 8(a). The conveyor selected was a slider bed type conveyor (Hytrol Model #TT "Thin Trough" conveyor) where the belt runs in a trough cross-section frame as shown in Figure 8(b)(i). This type of conveyor had the advantage that the probability of spillage was reduced and the belt, when in operation, would be relatively smooth running and vibration free. The conveyor weight was about 200 kilograms and was thus ideally suited for light duty use as in the present application. The overall bed length was 4.9 m and the belt was driven by a 3/4 HP motor at a speed of 25 cm/sec through a

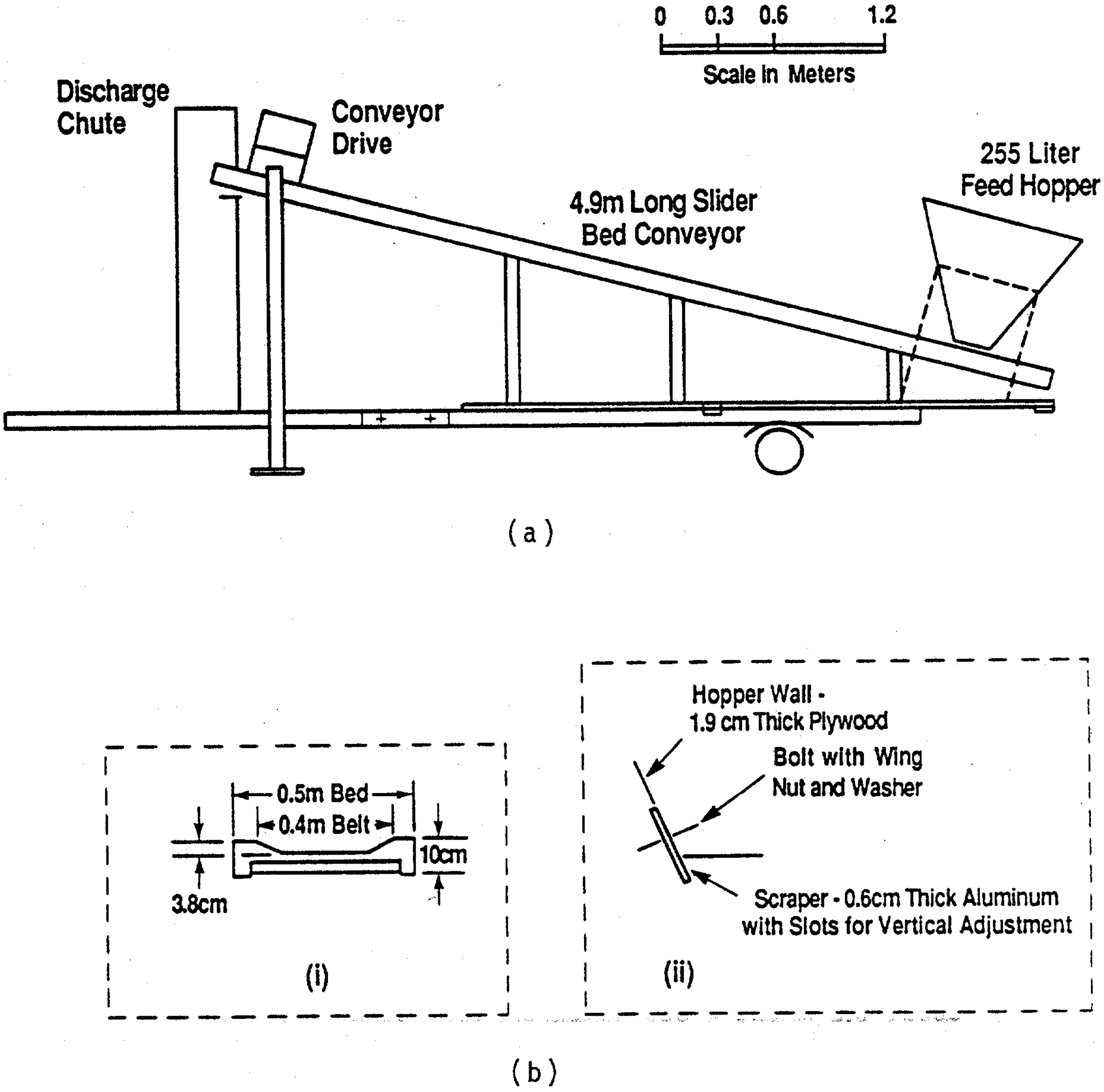


Figure 8. Intermediate scale field test setup.
(a) schematic of the material handling system.
(b) (i). cross-section of the conveyor.
(ii). fertilizer feed control method.

combination belt and chain drive. The conveyor belt speed could be changed by changing the sprocket in the chain drive.

The conveyor was mounted on the wooden support structure on the trailer at an angle of about 15 degrees by using 3 supports of appropriate height so that the conveyor discharge was about 1.8 m from the ground. The support heights were adjustable and allowed a variation of a few degrees in the conveyor inclination if such an adjustment was desired. The belt tension could also be adjusted by using tensioning screws provided. The feed hopper was held in place over the belt in a slotted angle frame so that the relative position of the hopper discharge with the belt surface was fixed. The hopper was made of 1.9 cm (3/4 inch) plywood and painted so as to resist attack by the fertilizer. It had an approximate capacity of 255 liters or, equivalently, about 250 kilograms of fertilizer. The downstream end of the hopper discharge was equipped with an adjustable aluminum slide plate as shown in Figure 8(b)(ii) to allow a measure of control over the product discharge rate from the hopper. The two sides and the upstream end of the feed hopper discharge were equipped with rubber skirts to prevent spillage and to allow fertilizer flow only in the direction desired. The support structure overhanging the trailer frame was propped up by concrete blocks when the system was in use.

The discharge end of the conveyor was semi-enclosed in an enclosure made of two 0.9 m sections of 0.51 m diameter galvanized. pipe. A slot was cut along the circumference so that the discharge end of the conveyor was enclosed and the fertilizer discharge was down the axis of the pipe. The top of the pipe was covered and bottom of the pipe was lower than the top of the discharge bin (Figure 9). This enclosure helped to protect the spray droplets and the fertilizer discharge stream from the effects of wind. In addition to the conveyor supports mounted on the trailer support structure, a fourth support made of 5 cm x 10 cm pressure treated wood and slotted angle iron was used to support the overhanging discharge end of the conveyor where the motor and drive weight was concentrated. This support was on the ground and was removable (Figure 10).

The fertilizer feed rate could be adjusted by changing the belt speed or by changing the feed hopper discharge characteristics. The conveyor was equipped with a single speed motor and so the belt speed could be varied only by changing the sprocket in the chain drive, It was much easier, on the other hand, to control the feed hopper discharge rate. The width of the hopper discharge was about 20 cm and so the bead laid out on the belt was about 20 cm as shown in Figure 11. However, the thickness of the bead could be easily varied by adjusting the slide plate. The feed rate could thus be varied from about 4 tons per hour to about 10 tons per hour by using the slide plate arrangement.

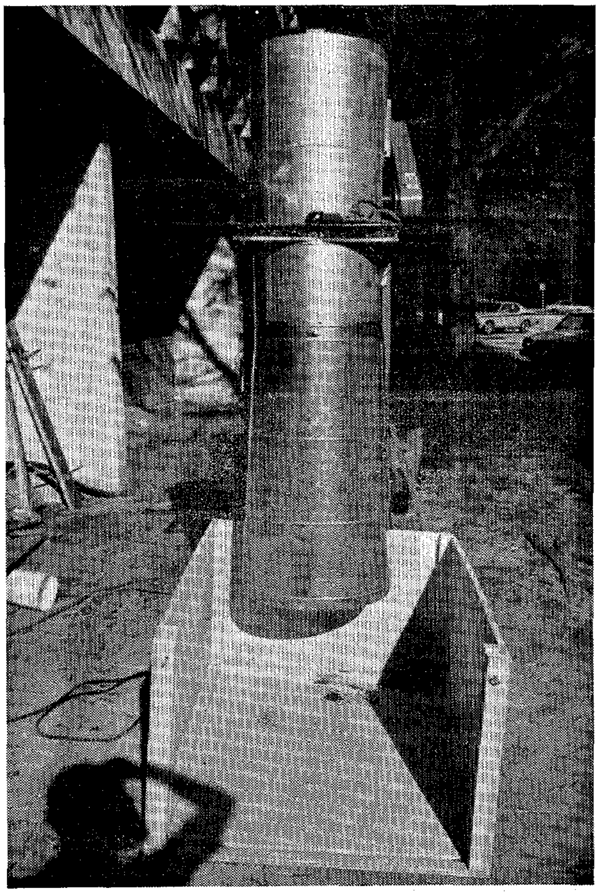


Figure 9. Photograph of the front view of the intermediate scale field test setup.

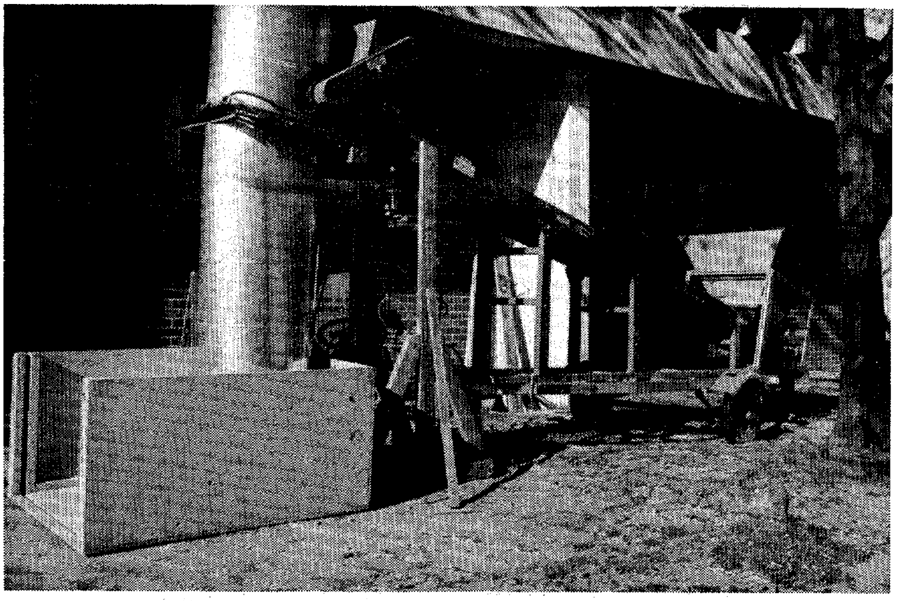


Figure 10. Photograph of the side view of the intermediate scale field test setup.

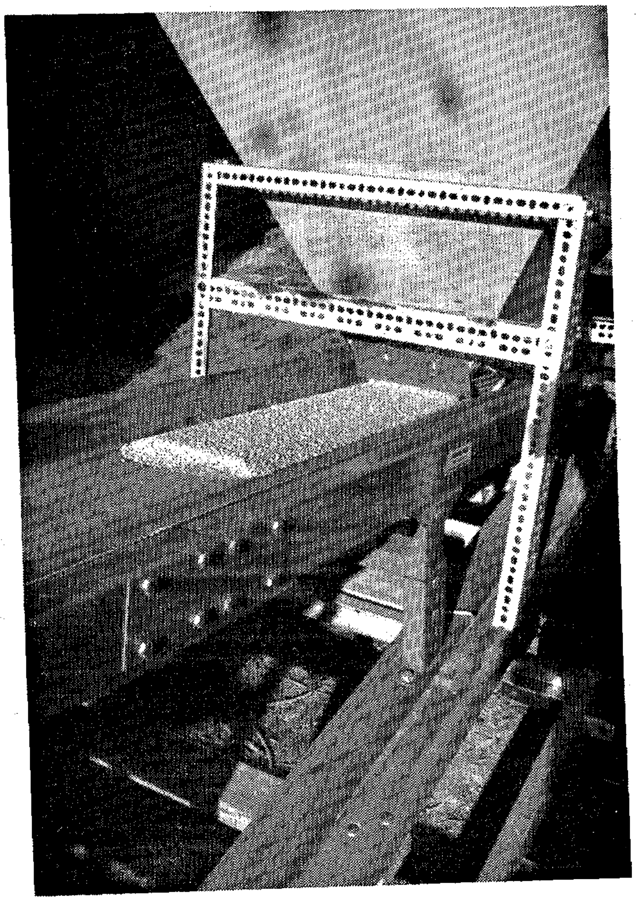


Figure 11. Photograph of the feed hopper discharge.

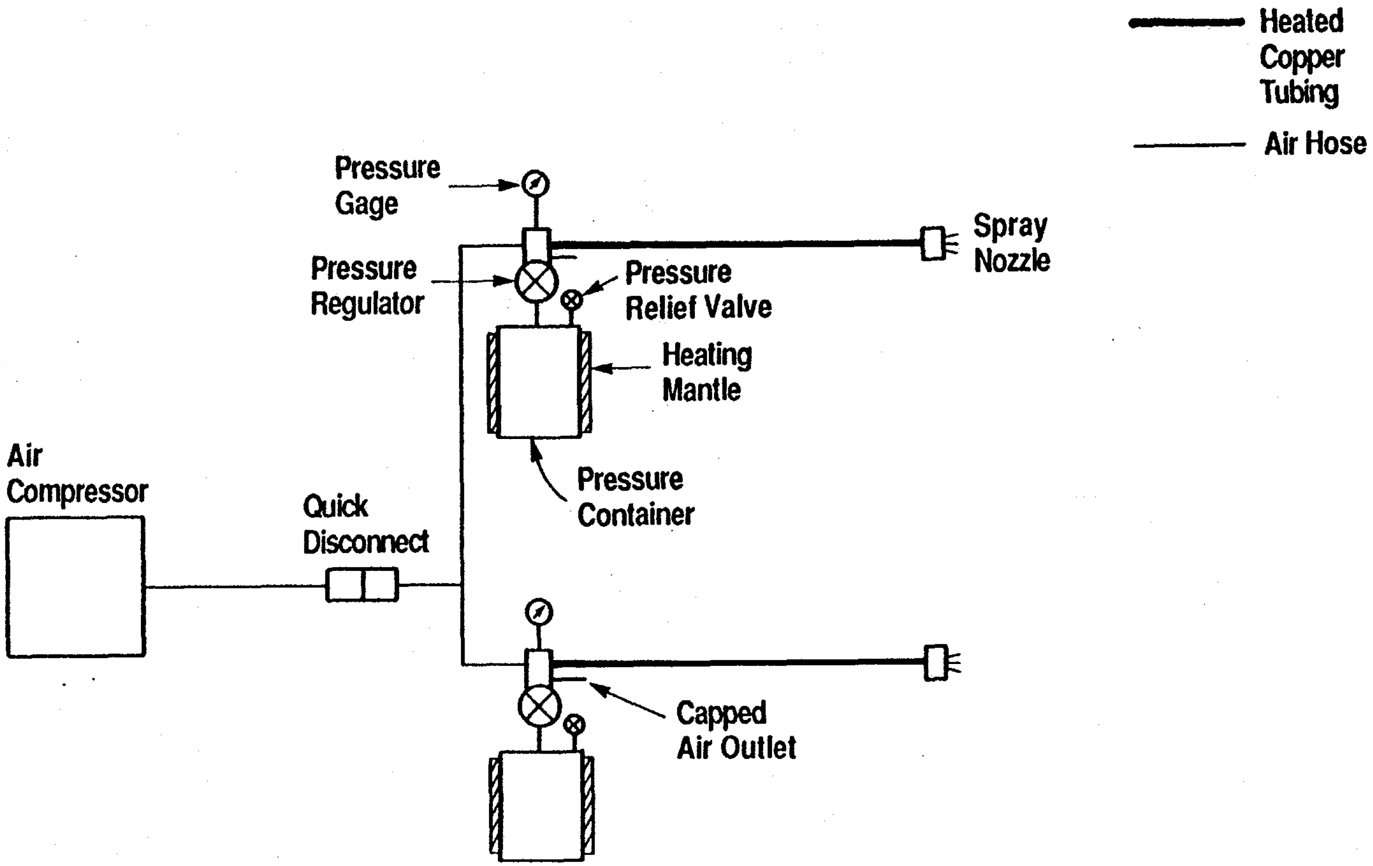


Figure 12. Dust suppressant spray system used for the intermediate scale field test setup.

A line drawing of the coating agent spray system is shown in Figure 12. The spray system was designed to transfer a controlled amount of coating agent on to the fertilizer granules. The basic spray system included a portable air compressor (Sears Model #919.156580), two Fitz & Fitz 1.9 liter pressure containers and 2 nozzles. The nozzles used were of the pressurized liquid type (Spraying Systems Catalog #1/4TT-730039). The compressed air supply was divided into two streams, each passing through a pressure container. The pressure containers were rated at a peak liquid pressure of about 414 kPa (60 psig). Each pressure container had two outlets used to provide separate air and liquid flows for air atomizing nozzles. The air outlet was capped off since the pressurized liquid nozzles did not need atomizing air. All liquid lines were 9.5 mm (3/8 inch) diameter copper tubing. The copper tubing and nozzles were heated by heating tape while the pressure containers were heated by heating mantles. All heaters were controlled by variable transformers. Since petrolatum waxes were the primary coating of interest, the pressure containers were maintained at a temperature high enough to keep the petrolatum waxes molten and liquid lines were heated to prevent solidification in the lines. The liquid feed was controlled by adjusting the regulator pressure on the pressure containers. The nozzles were in an opposing jet arrangement about 25 cm from each side of the fertilizer discharge stream and about 15 cm below the discharge end of the conveyor.

At least 3 buckets (about 70 kilograms) of fertilizer were used in each test. Three 5 kilogram samples of the uncoated fertilizer were first prepared in the standard manner. The remaining uncoated fertilizer was then poured into the feed hopper. The line heaters and heating mantles were all energized and the nozzles were calibrated prior to the test by timing the consumption of a known amount of hot water. This also helped to heat the lines and clean them. Hot water was poured into the pressure containers and the water temperature was maintained by means of heating mantles. The wax being tested was weighed out into two plastic bottles which were then placed in a beaker of boiling water till the wax was completely melted. The bottles were then placed in each of the two pressure containers. In this manner the wax was not subjected to excessive local heating, the pressure containers were easily cleaned after use, successive tests could be conducted more rapidly and cross contamination was not a problem. After allowing sufficient time for the nozzles and fluid flow lines to heat up and setting the hopper discharge, the conveyor was turned on. The wax spray was initiated so as to coincide with the fertilizer discharge from the conveyor. When all the fertilizer was used up the wax spray was discontinued by disconnecting the air supply at the quick disconnect and relieving the line pressure by using the pressure relief valve on the pressure container. Operating parameters such as the hopper discharge setting, fertilizer weight, weight of wax consumed, wax temperature and the wax and fertilizer feed times were noted. During the test the fertilizer was discharged into the discharge bin. After the test was complete the fertilizer in the bin was stirred by using a shovel and then stored in 19 liter buckets. Two to three test samples of coated fertilizer were then made in the standard manner for later testing. To verify that the nozzles did not plug during the test the nozzle calibration for water was rechecked. At this point the next test , if planned, was performed by simply replacing the wax sample bottles and recharging the feed hopper with a new batch of uncoated fertilizer.

Discussion

The development of the ISFT setup and operating procedures was an evolutionary process. Preliminary tests were conducted without the discharge enclosure, but excessive fertilizer dust and wax spray blow-off led to the addition of the discharge enclosure.

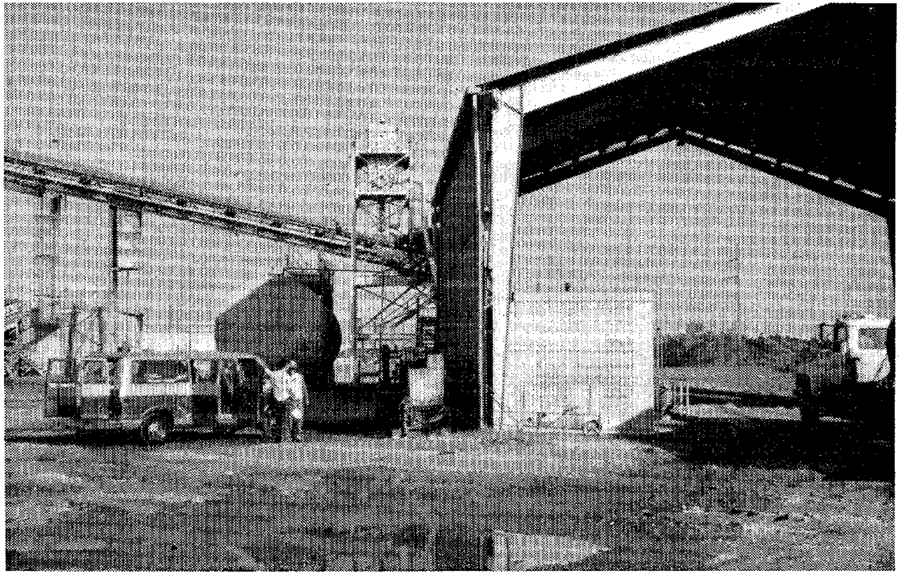
Before reaching a decision on the use of the pressurized liquid nozzles, air atomized nozzles were evaluated. Both internal mix and external mix nozzles were considered. In using the air atomizing nozzles the air outlet from the pressure container was connected to the nozzle by an air hose. In the internal mix type nozzle, compressed air and liquid are mixed within the nozzle and then ejected from the nozzle. However, wax solidification due to excessive cooling and losses by overspray due to extreme atomization were continual problems. Modification of the setup by regulating the air pressure to the nozzle did not significantly improve the problem nor did the use of 4 nozzles, each with half the capacity of the nozzles in the 2 nozzle arrangement. The external mix nozzles did not have the same wax solidification problem but overspray losses were still excessive. With the pressurized liquid nozzles, nozzle plugging due to wax solidification was no longer a problem and overspray losses were much reduced due to the coarser droplets produced.

The two nozzles were placed 15 cm below the discharge end of the conveyor, one on each side of the fertilizer discharge. Because of the close proximity of the nozzle to the underside of the belt, over a period of time the belt had a tendency to get coated with wax and so a deflector shield was installed. The nozzles were originally placed 15 cm from the fertilizer surface but at this distance the spread of the spray was insufficient. to cover the width of the fertilizer discharge. So, the nozzles were moved back to a distance of 25 cm from the fertilizer discharge.

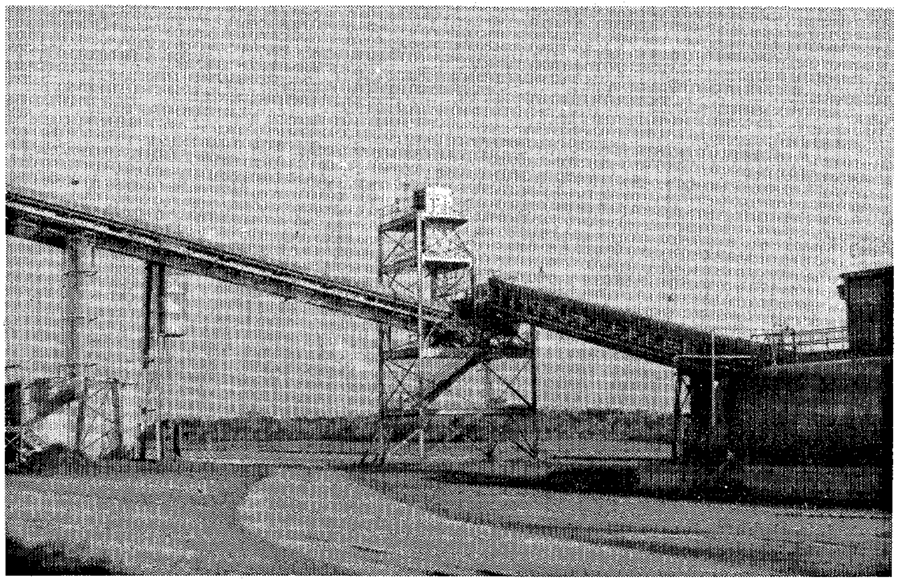
FULL SCALE FIELD TESTS

Apparatus and Operating Procedure

Full scale field tests were conducted at a fertilizer shipping facility (Agrico Chemical Co., Pembroke Road, Gibsonton, Florida). This facility handles granular triple super phosphate (GTSP) and phosphate rock. The GTSP was transported to this facility from the fertilizer plant by trucks in a travel time of about 1 hour. The fertilizer handling setup was as shown in Figures 13 and 14(a) with air samplers placed within the storage building as shown in Figure

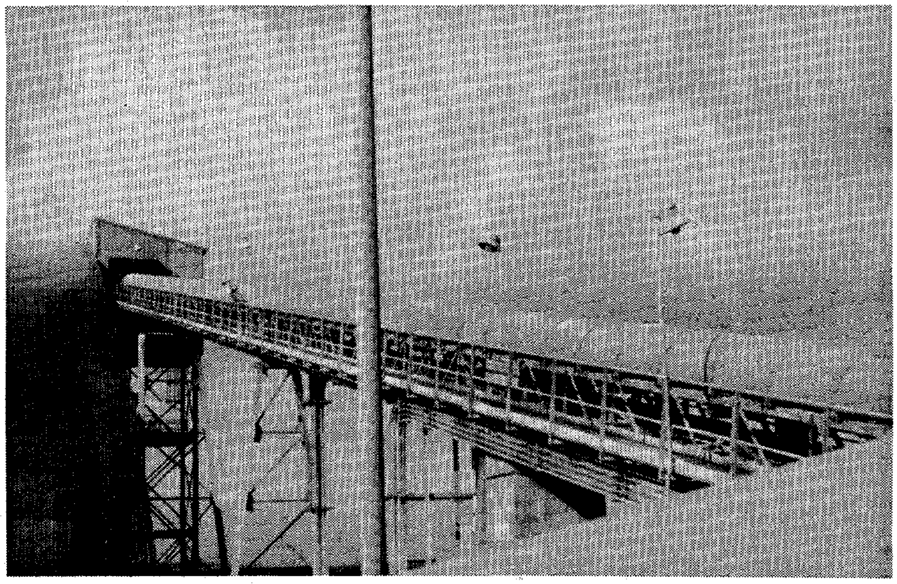


(a)



(b)

Figure 13. Photographs of the full scale field test facility.
(a) truck unloading station (b) transfer point #2 (c) transfer point #3.



(c)

Figure 13. Continued.

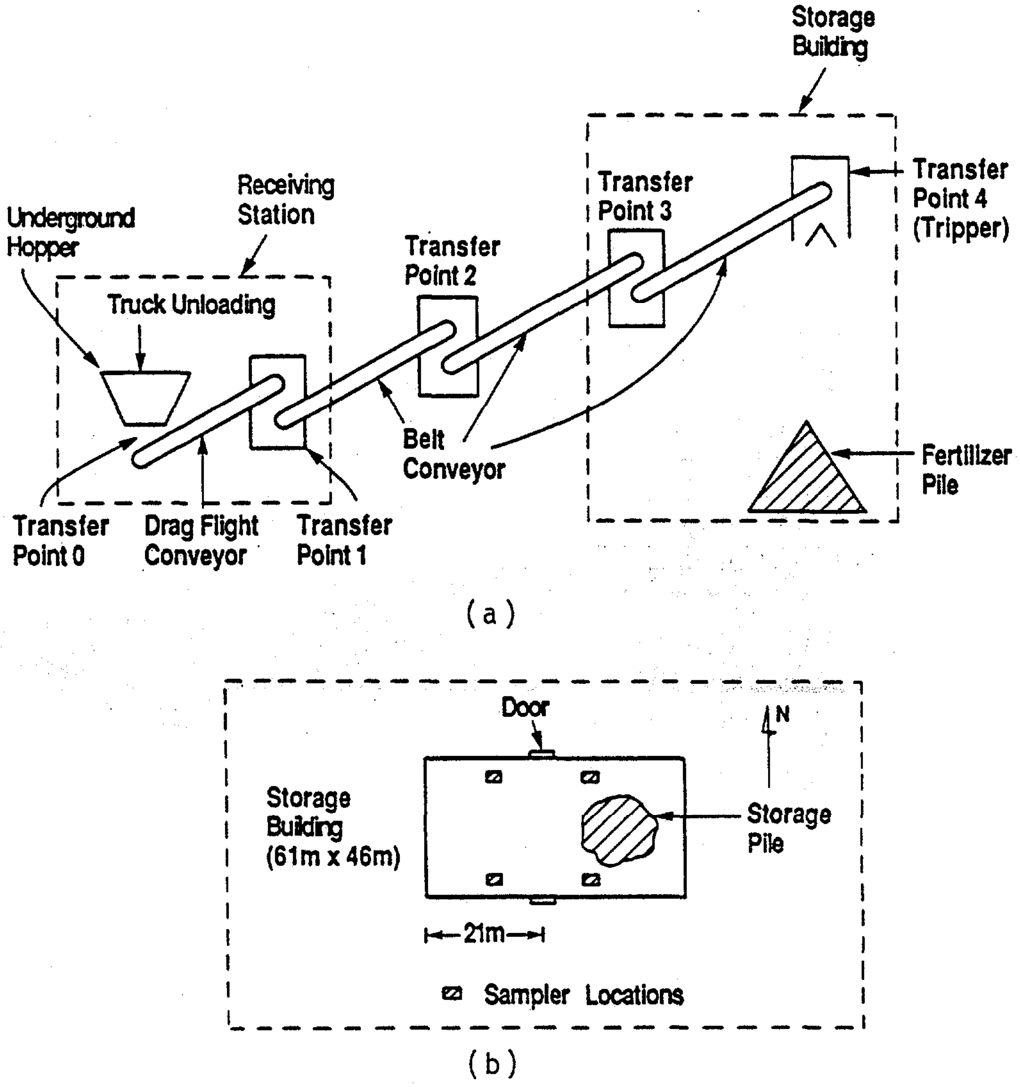


Figure 14. Details of the full scale field test facility.
(a) fertilizer handling system.
(b) air sampler locations.

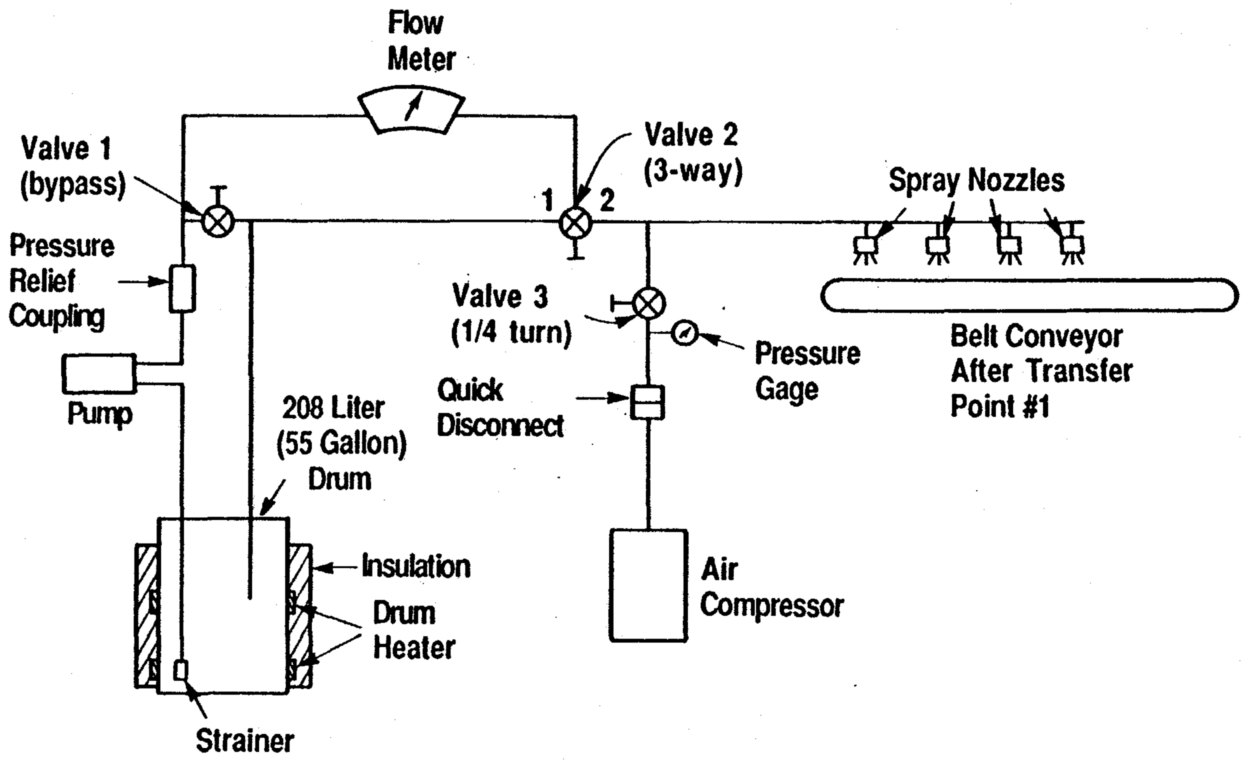


Figure 15. Dust suppressant spray setup for the full scale field tests.

14(b). The nominal fertilizer handling rate was 250 tons/hour.

The coating agent spray system was designed within the facility constraints to provide a maximum spray rate of about 19 liters/min (5 gpm) at about 414 kPa. Petrolatum waxes were acquired in 208 liter (55 gallon) drum quantities. The spray setup was as shown in Figure 15. The pump used was a Liquiflo Series 86 Eccentric Impeller pump with a 3/4 H.P., 110V motor. The flowmeter used was an Erdco Series 400 vane-type flowmeter. Valve 1 was a bypass valve used as flow control, Valve 2 was a 3-way valve used to switch the flow from recycle mode to spray mode and Valve 3 was a 1/4 turn valve used to control the supply of compressed air. All flow lines were 1.9 cm and 1.3 cm. black iron pipe and were heat traced with 220V heating tape and insulated. Four nozzles were aligned 46 cm (18 inch) apart along the axis of the belt conveyor between transfer point #1 and #2.

The drum of wax was heated by 2 drum heaters (Briskeat Catalog #SRL-A-DHC-1200) with integral temperature controllers being used to set the temperature at about 150°C and insulated with fiberglass insulation. The drum heating process was begun 12 to 24 hours prior to actual use. The line heaters were then energized and heating was controlled by a variable transformer. The pump intake was equipped with a suction filter (Spraying Systems Catalog #HSW) to strain out particulate matter. Four pressurized liquid type nozzles were cleaned in hot water and mounted in the spray manifold. Each nozzle was equipped with a 50 mesh strainer. Valve 2 was first set to position 1 to permit use of the system in recycle mode, Valve 1 was opened halfway and the pump was then turned on. The liquid wax was permitted to circulate through the system so that all the lines and components could be evenly heated. The pump intake was securely tightened so as to prevent air infiltration which could cause the liquid wax to foam. A yardstick was taped to the inside of the drum to permit a secondary measure of liquid consumption.

The oil supply to the existing oil spray system was first shut off. Once a truck started unloading its load and the fertilizer appeared on the belt between transfer point #1 and #2, the fertilizer was allowed to run uncoated for about 45 seconds. The liquid wax was then switched from the recycle mode to the spray mode by switching Valve 2 to position 2. Valve 2 was then adjusted to set the flow rate at the required level as indicated by the flowmeter. It took 30 seconds for material transfer from transfer point #1 to transfer point #2, 45 seconds for material transfer from transfer point #2 to transfer point #3 and 30 seconds for material transfer from transfer point #3 to transfer point #4. A bucket was half-filled with uncoated fertilizer sampled at transfer point #2 and then 2 buckets of coated fertilizer were sampled at transfer point #4 a minute after wax coated product appeared. Once the coated samples were collected Valve 1 was used to reduce the liquid spray rate by recycling part of the pumped liquid back to the reservoir and Valve 2 was set to position 1, to put the spray system in recycle mode. The half filled bucket of uncoated fertilizer was then completely filled at transfer point #2. By measuring the fall of the liquid level in the drum and the time of consumption, the application rate was calculated as a check of the flowmeter. If more than a few minutes wait was anticipated between runs compressed air was blown through the nozzles by switching Valve 3 to the "on" position. Compressed air was provided by a portable air compressor (Sears Model #919.156580). In this manner, nozzle plugging was avoided. At the end of a series of tests hot water was circulated through the spray system in the recycle mode to clean out as much wax from the lines as possible. No attempt was made to spray water through the system in the spray mode because of possible caking problems which could occur in the vicinity of the conveyor.

The coated samples collected were brought back to the laboratory and 5 kg test samples were prepared for further analysis in the standard manner.

Discussion

The location for conducting the field test was chosen based on a number of factors, the most important of which was familiarity with the facility. Power outlets were easily accessible, fertilizer sampling locations were convenient and the design of the fertilizer handling system was such that the coating spray system could be situated in a compact way not too far away from the spray location.

The pump selected was of an eccentric impeller design with a high density polymer impeller. The maximum pressure and temperature ratings were 1103 kPa and 90°C, respectively. This pump was considered ideal for the present application because the liquid to be pumped was clean and a lubricant. No pressure gages were installed because of the possibility of fouling the internal parts of the gage by solidifying wax. For this same reason a "sight gage" type vane flowmeter was selected for flowrate measurement. The deflection of the vane was a measure of flow rate. In addition, line plugging could be signaled by the "see through" window in the flowmeter. Pressure relief was provided by a plastic coupling rated at 828 kPa.

The pump and compressor both had 110 V motors and the power supply was routed through a 15 amp circuit breaker. As a result, when the compressed air tank was full the cycling of the compressor caused the breaker to trip due to the high starting current of the compressor motor. Thus, in order to operate the pump and compressor simultaneously, a bleed valve was installed in the compressor outlet so that the compressor would run continuously without shutting off.

Various combinations of spray location and nozzle size were evaluated and the results are discussed in a later chapter.

4. RESULTS AND DISCUSSION

Extensive evaluations were conducted during the course of this study. Results presented in this chapter are divided into separate sections: laboratory tests, intermediate scale field tests (ISFT) and full scale field tests (FSFT). Criteria for the selection of dust suppressants are also discussed.

LABORATORY TESTS

Effect of Temperature on Test Samples

The effect of temperature on granular triple superphosphate (GTSP) and diammonium phosphate (DAP) was studied. Three 30-gram samples of GTSP, three 20-gram samples of GTSP and three 30-gram samples of DAP were weighed out in 95 mm diameter aluminum dishes and placed in an oven (Precision Model #17) at 105°C. Sample weights were measured with a single pan electronic balance (Sartorius Model #2355). The measured weight change as a function of time was as shown in Figure 16.

The DAP samples showed a consistent loss in weight with no sign of equilibration over the time period considered. This loss in weight was accompanied by a strong smell of ammonia in the vicinity of the oven. From this observation it was concluded that the DAP granules were undergoing a process of breakdown and subsequent deammoniation.

The GTSP granules also exhibited a continuous weight loss as a function of time. However, the rate of weight loss was significantly reduced after the first 24 hours. This phenomenon was probably due to accelerated chemical reactions within the granules and subsequent breakdown by a process called phosphate reversion (Bookey and Raistrick, 1960; Slack, 1968).

In addition, when test samples of GTSP were subjected to elevated temperatures over a period of time the moisture content of the granules was significantly reduced. Because of this reduction in moisture content the measured emission factor (Table 4) was greatly increased. Similar behaviour can be expected with test samples of other fertilizers.

Effectiveness of Test Sample Preparation Method

Five kilogram test samples were prepared from a given batch of fertilizer using the technique described earlier. As standard practice at least two test samples from each batch of product were tested in an uncoated state. The average emission factor for the

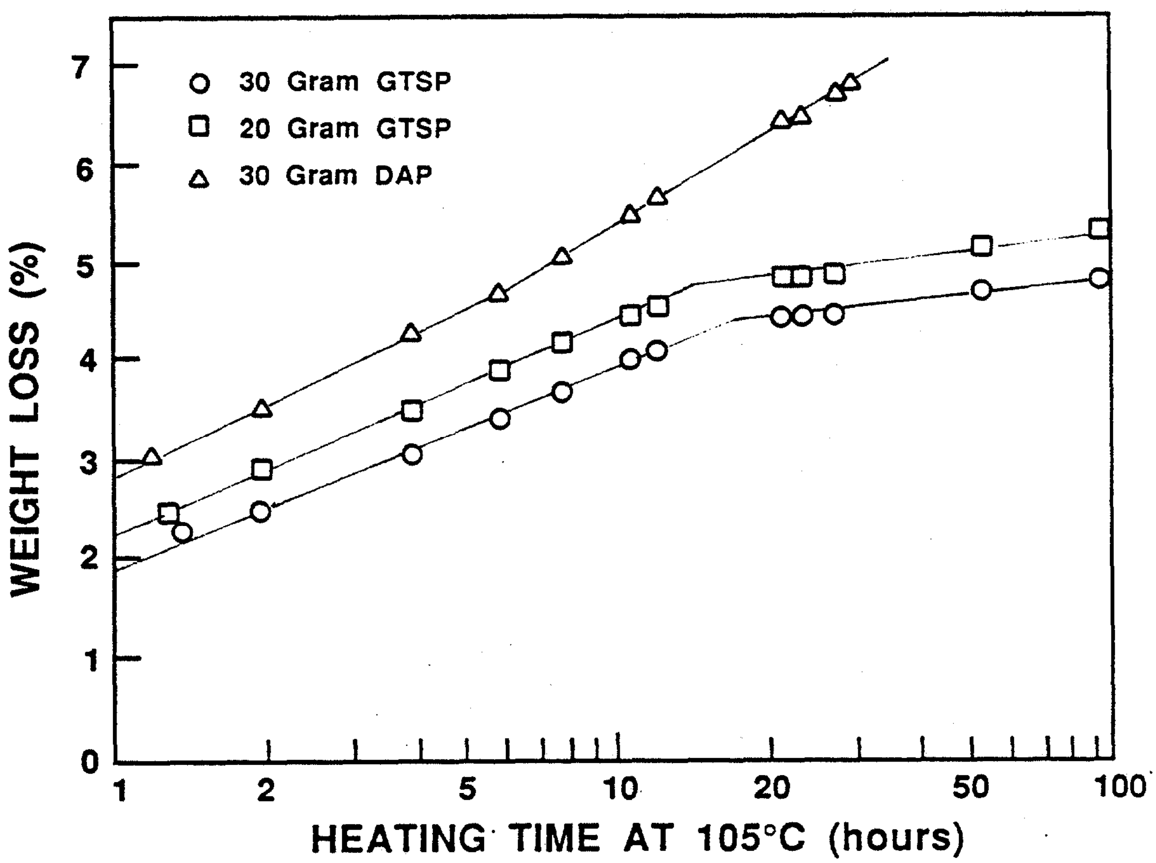


Figure 16. Weight loss due to heating of GTSP and DAP samples as a function of time.

TABLE 4

Effect of Heating on the Emission Factor of GTSP Samples

Sample I.D.	Sample Treatment	Moisture Content (%)	Emission Factor (g/kg)
R14	None	1.4	0.0166
R3	Heated	0.8	0.0652
AGTSP127	None	0.96	0.0433
AGTSP134	Heated	0.54	0.0628

batch and the deviation of the emission factor of each individual sample from the average emission factor was calculated. This average emission factor represents the baseline emission level prior to treatment while the deviation is a measure of relative product homogeneity with regard to dust emissions.

Specific results for test samples from three batches of fertilizer are shown in Table 5. A scatter diagram of measured deviation for 178 samples of fertilizer from 89 distinct batches is shown in Figure 17. From these results it is evident that the sample preparation method and the measurement method were very effective. The average deviation from the average emission factor was about 3.5 % and 97% of the samples had a deviation of less than 10 % from the average emission factor. Thus, the calculated average uncoated emission factor for a batch can be considered to be representative of the whole batch. In addition, since dust suppression effectiveness is a function of the ratio of coated to uncoated emission factor, an accurate value of uncoated emission factor improves the quality of the calculated effectiveness.

Because of the reproducibility of the emission factor measurements, this technique was used to screen materials from different sources (Table 6). Dust emission factors in the 0.005 g/kg to 0.1 g/kg range were measured for various products from many sources. This technique was also used to monitor the variation of product quality, as shown in Table 7. For a particular source the measured dust emission factor varied between 0.03 g/kg and 0.08 g/kg over a period of time.

Granule and Dust Characteristics

Moisture, both surface and chemically bound, is present in the fertilizer granules and, as discussed earlier, sustained high temperatures lead to moisture loss and severe increases in dust emissions. This suggests that increased moisture content should have the opposite effect. The validity of the above observation was borne out by the results shown in Figure 18. Four samples of GTSP from batch A and three samples of GTSP from batch B were used. For batch A, sample #1 was dried, sample #2 was left untreated and sample #3 and sample #4 were sprayed with known amounts of water to raise their moisture content. For batch B, sample #1 was left untreated and sample #2 and sample #3 were sprayed with known amounts of water to raise their moisture content. The results of drop tests clearly show that just a 20 % increase in moisture content resulted in significant decreases in dust emission factor and it appeared that a moisture content of about 1.5 % for GTSP samples could be very beneficial as far as dust emission reduction was concerned.

Since moisture plays such an important role in determining product dustiness, a test was conducted to establish if there was any variation in measured moisture content as a function of time of storage. Three 2- gram samples were taken on 3 successive days from a

TABLE 5

Effectiveness of the Test Sample Preparation Method

Product Type	Sample I.D.	Average Emission Factor of Test Sample (g/kg)	Average Emission Factor of Batch (g/kg)	Deviation from Average (%)
GTSP	AGTSP8	0.0387	0.0414	-6.5
	AGTSP7	0.0405		-2.2
	AGTSP6	0.0449		+8.5
DAP	GODAP11	0.0918	0.0981	-6.4
	GODAP1	0.1007		+2.7
	GODAP6	0.1019		+3.9
GTSP	IGTSP7	0.0229	0.0251	-8.8
	IGTSP1	0.0247		-1.6
	IGTSP8	0.0278		+10.8

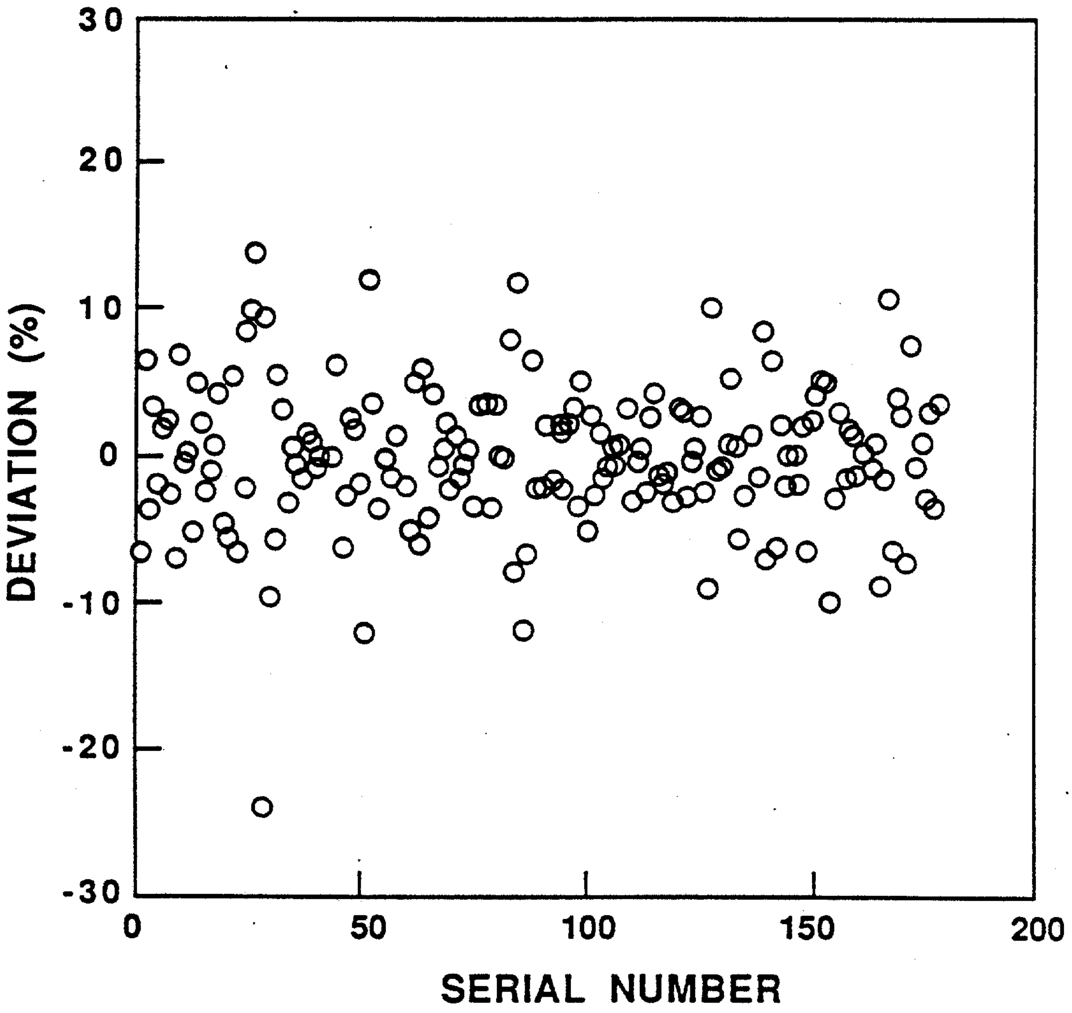


Figure 17. Deviation of the emission factor of individual samples from the average emission factor for that batch.

TABLE 6

Examples of Emission Factors for Various Products

Product Type	Average Emission Factor (g/kg)
AGTSP	0.0506
GADAP	0.0093
IGTSP	0.0096
IDAP	0.0082
GGTSP	0.0158
GODAP	0.0981
FDAP	0.0309
Phosphate Rock	0.1362
White Sand	0.0133
Sulfur	0.0877

NOTE: AGTSP, IGTSP and GGTSP are GTSP samples from three different manufacturers.
GADAP, IDAP, GODAP and FDAP are DAP samples from four different manufacturers.

TABLE 7

Variation of Product Quality for GTSP Samples

Batch I.D.	Average Emission Factor (g/kg)	Overall Average (g/kg)
A	0.0506	
B	0.0720	
C	0.0347	0.0457
D	0.0331	(gsd = 0.0143)
E	0.0405	
F	0.0435	

NOTE: The 6 batches represent product acquired from the same manufacturer on different occasions. "gsd" is the geometric standard deviation.

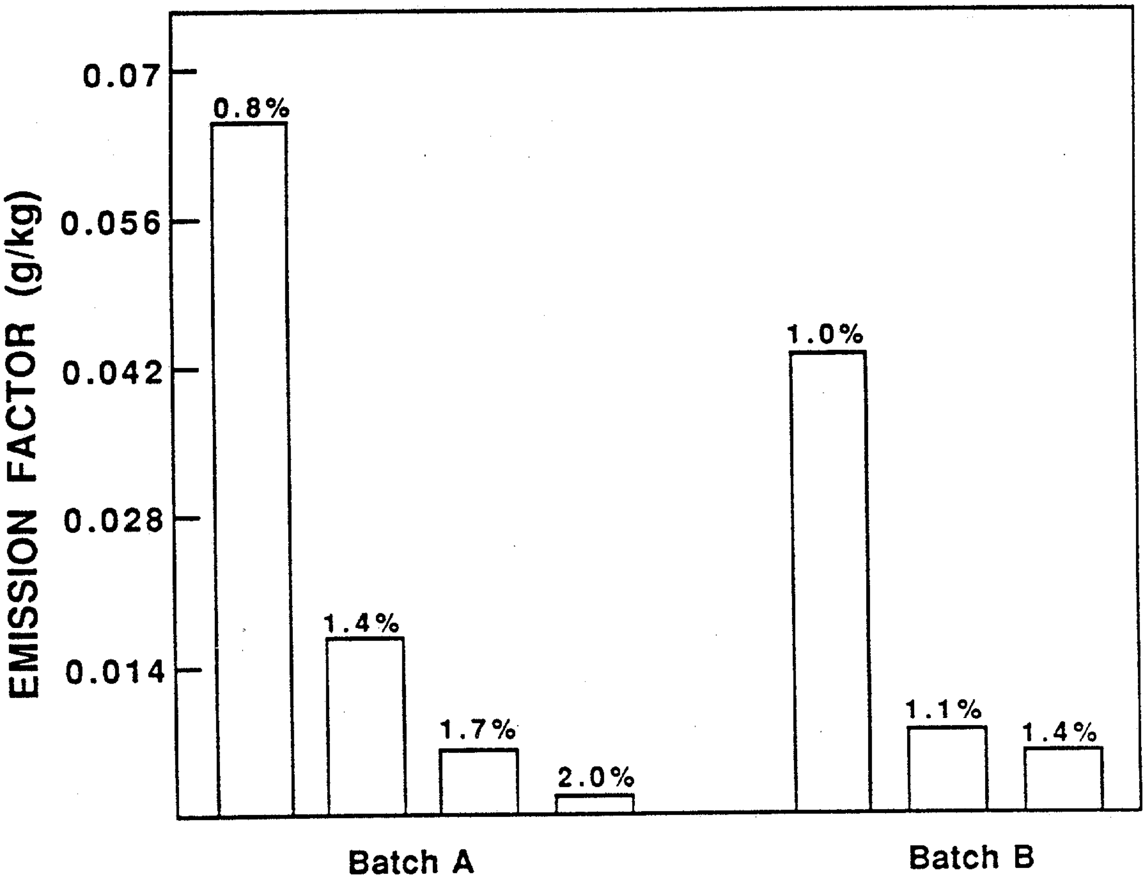


Figure 18. Effect of the moisture content on the emission factor of GTSP samples.

5-kg test sample of GTSP and moisture content was measured in the manner described earlier. Results in Table 8 show that there was no significant change in moisture content over the time period considered and, correspondingly, the dust emission factor can be considered to be unaffected by storage, at least in the short term.

The standard test procedure for the measurement of moisture content specifies 2-gram test samples. But, a series of tests with larger sample sizes were carried out to determine if sample size was a significant factor in the measurement. Results of tests with untreated fertilizer (Table 9) show that the measured moisture content was quite insensitive to sample size when the fertilizer was not sprayed with water after manufacture. However, if in an effort to increase moisture content, water was externally sprayed on the 5-kg test sample, the smaller 2-gram sample results in erroneous and scattered results (Table 10). On the other hand, 10-gram samples resulted in a significantly better determination of measured moisture.

Size distributions of DAP, GTSP and MAP samples from different manufacturers were determined by sieving 100-gram samples for 10 minutes in a Gilson Model #SS-15 Sieve Tester. Calcined phosphate rock and fine grain white sand were also sieved as a comparative measure. Results of these sieving tests (Table 11 and Table 12) show that the granular product was generally in the 2.0 mm to 2.5 mm range and the size distribution was fairly narrow. The various size fractions were tested for granule hardness or crushing strength by the TVA method described earlier. Results show that the measured crushing strength increased with increasing granule size as has been observed elsewhere (Jager and Hegner, 1985). For the samples tested, MAP granules were stronger than DAP granules, which were, in turn, stronger than GTSP granules (Figure 19).

Since product dustiness was determined by drop tests, experiments were conducted to determine if granule fracture, a possible mode of dust generation, was measureable. One-hundred-gram samples were extracted from 5-kg test samples before and after a complete "drop test" and sieved in the standard manner. The difference in measured size distribution for DAP and GTSP samples was not significant and could have been due to sampling variabilities (Table 13). This same behavior was exhibited by phosphate rock and white sand. However, though the dry sieving technique used was not sensitive enough to determine if granule fracture occurred, the results do show that it was not significant.

Similar tests were conducted with prilled sulfur, a brittle material, and the results are presented in Figure 20. With increased handling the size distribution exhibited a distinct shift toward the smaller particle sizes with a corresponding increase in the fraction of small particles. Examination of the samples also verified that significant granule fracture occurred. A similar process has been found to occur with coal, char particles and detergents (Arastoopour and Chen, 1983; Goodwin and Ramos, 1987; Knight and Bridgewater, 1985).

TABLE 8

Stability of the Moisture Content of Stored GTSP Samples

Day	Sample Number	Moisture Content (%)	Average Moisture Content (%)
1	1	0.82	0.73
	2	0.66	
	3	0.71	
2	1	0.69	0.75
	2	0.75	
	3	0.82	
3	1	0.74	0.73
	2	0.76	
	3	0.70	

TABLE 9

Effect of Sample Size on the Measured Moisture Content of Untreated GTSP Samples

Sample I.D.	Sample Size (g)	Moisture Content (%)	Average Moisture Content (%)
1	20	1.10	1.13
2	20	1.17	
3	10	1.06	1.07
4	10	1.07	
5	2	1.13	1.16
6	2	1.20	

TABLE 10

Effect of Sample Size on the Measured Moisture Content of Treated GTSP Samples

Sample I.D.	Serial Number	Sample Size (g)	Measured Moisture Content (%)	Average Moisture Content (%)	Treatment
AGTSP109	1	2	0.93	1.01	None
	2	2	1.10		
AGTSP108	1	2	0.94	1.11	Water
	2	2	1.28		
AGTSP101	1	2	1.26	1.20	Water
	2	2	1.14		
AGTSP109	1	10	0.96		
	2	10	1.04	0.99	None
	3	10	0.98		
AGTSP108	1	10	1.08		
	2	10	1.14	1.11	Water
	3	10	1.12		
AGTSP101	1	10	1.44		
	2	10	1.42	1.43	Water
	3	10	1.42		

NOTE: Expected Moisture Content: AGTSP108 - 1.2 %
AGTSP101 - 1.5 %

TABLE 11

Granule Size Distribution of Samples of Various Fertilizers

Granule Size (mm)	Sample I.D. AGTSP8 (wt. % <)	IMCGTSP6 (wt. % <)	IMCDAP14 (wt. % <)	GRGTSP14 (wt. % <)	GRODAP8 (wt. % <)	FDAP2 (wt. % <)	GAMAP2 (wt. % <)	GAGTSP8 (wt. % <)
3.35	91.5	93.0	97.4	99.8	100.0	99.4	99.1	93.0
2.36	33.5	19.4	74.5	83.6	91.0	81.7	61.6	18.4
1.70	1.3	0.62	18.8	34.2	63.3	19.5	14.1	0.09
1.18	0.02	0.03	0.33	2.5	27.1	2.3	1.6	0.02
0.85	0.02	0.02	--	2.02	4.7	0.18	0.19	0.01
0.425	0.02	0.02	--	--	0.05	0.04	0.12	--
MMD (mm)	2.60	2.65	2.02	1.85	1.50	2.00	2.10	2.60
GSD	1.19	1.18	1.24	1.28	1.40	1.23	1.24	1.20

NOTE: Samples are GTSP, MAP and DAP from 5 different manufacturers.
MMD is the Mass Median Diameter.
GSD is the Geometric Standard Deviation.

TABLE 12

Size Distribution of Samples of Some Non-granular Materials

Granule Size (μm)	Phosphate Rock (wt. % <)	White Sand (wt. % <)
850	94.2	100.0
425	89.6	99.8
212	46.5	72.8
106	2.6	1.3
75	0.44	0.03
53	0.12	--
MMD (μm)	250	190
GSD	1.60	1.32

NOTE: MMD is the Mass Median Diameter.
GSD is the Geometric Standard Deviation.

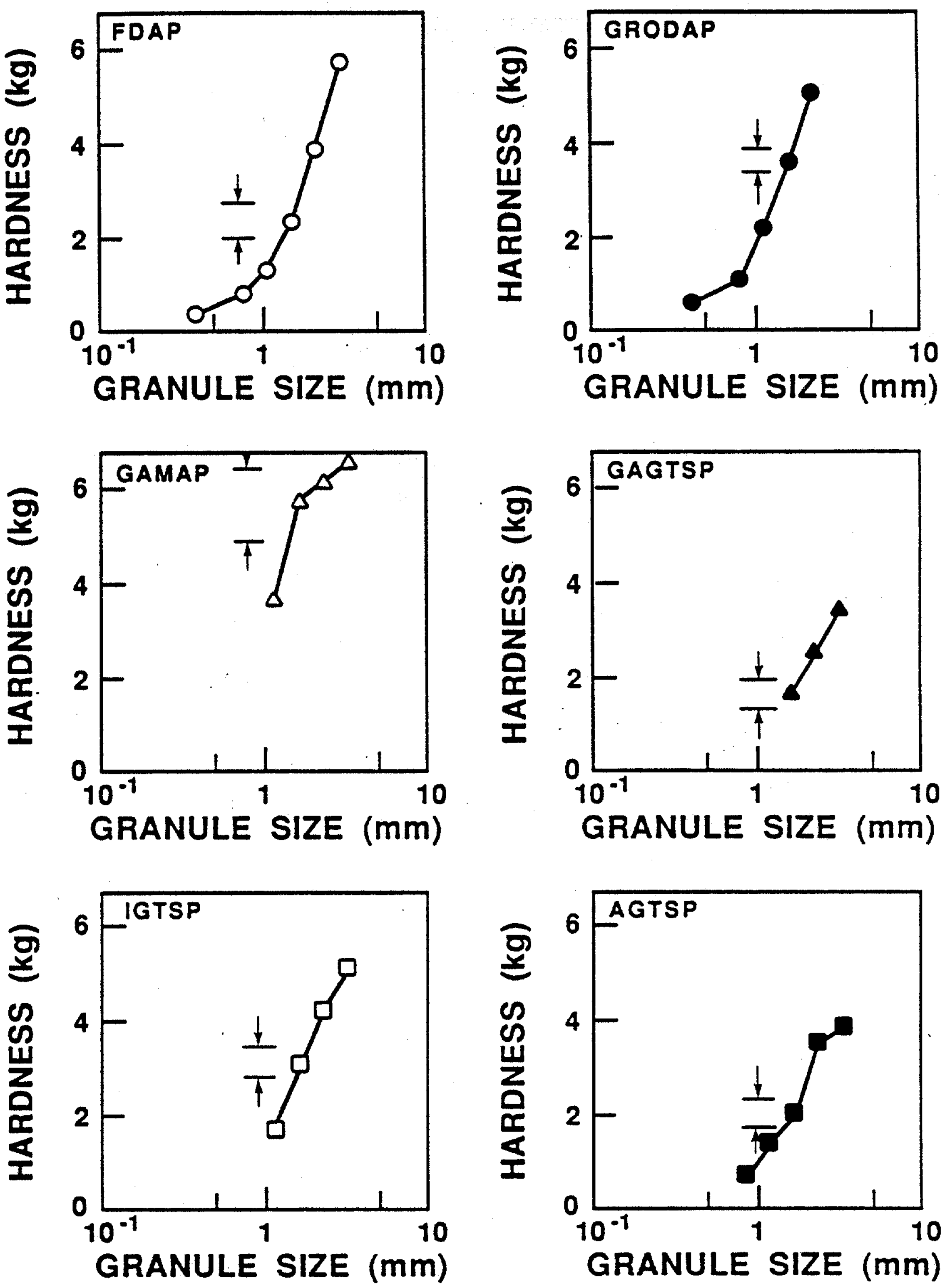


Figure 19. Hardness of granules of various fertilizers.

TABLE 13

Effect of "drop tests" on Product Size Distribution

(a). Granular Materials

Granule Size (mm)	IDAP14 Before wt. % <	IDAP14 After wt. % <	IGTSP6 Before wt. % <	IGTSP6 After wt. % <
3.35	97.4	95.8	97.1	97.6
2.36	74.4	71.3	48.3	51.3
1.70	18.8	18.4	6.2	8.4
1.18	0.33	0.39	0.30	0.36
0.85	--	0.02	0.02	0.01
0.425	--	0.01	--	0.01
MMD (mm)	2.02	2.10	2.22	2.30
GSD	1.24	1.24	1.23	1.22

(b) Non-granular Materials

Particle Size (μm)	White Sand Before wt. % <	White Sand After wt. % <	Phosphate Rock Before wt. % <	Phosphate Rock After wt. % <
850	100	100	93.1	94.3
425	99.8	99.8	85.2	87.8
212	73.1	76.3	45.9	49.3
106	1.2	1.3	2.6	3.2
75	0.03	0.02	0.42	0.60
53	--	--	0.09	0.15
MMD (μm)	190	190	255	245
GSD	1.32	1.32	1.61	1.61

NOTE: MMD is the Mass Median Diameter.
GSD is the Geometric Standard Deviation

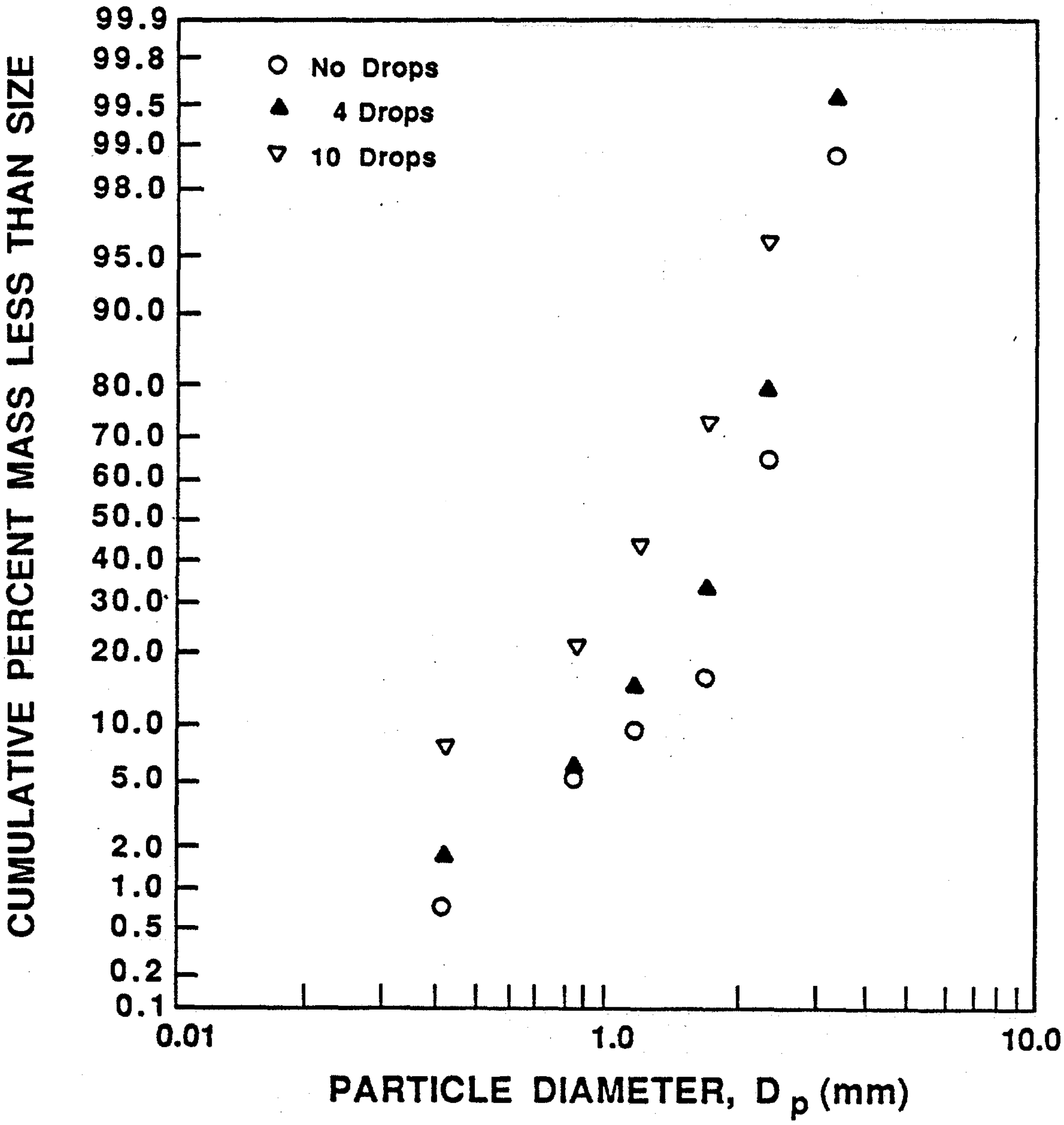


Figure 20. Effect of handling on the size distribution of prilled sulfur.

Further study of the drop-wise change in dust emission factor (Figure 21) indicated the significant difference in response to handling between sulfur and the other products. The dust release process is a function of the fracture tendency of materials. Dust release from sulfur was due to significant breakage of prills while with the other materials fracture was not a significant source of dust. The dust was probably due to fines in the sample, breakage of crystal growths on the granule surface (Figure 22) and release of dust bound to granule surfaces by physical forces. The existance of crystal growths has also been documented elsewhere (Hoffmeister, 1979; Kjohl, 1976; Jager and Hegner, 1985).

The dust size distribution for various products was measured using the technique described earlier. Products used included GTSP, DAP, phosphate rock and white sand. Tests were initially conducted with the Andersen and University of Washington Mark III multi-stage impactors. These tests were not successful because the optimum operating characteristics of the multi-stage impactors were not compatible with the drop test apparatus and operating conditions. The above multi-stage impactors were designed to measure particle size distributions in the approximate 0.4 µm to 15 µm size range with a sample flow rate of about 7 liters/min to 21 liters/min. To ensure that a representative sample was collected, isokinetic sample conditions had to be maintained by an appropriate selection of nozzle diameter and sample flow rate and this required the use of a highly flared short nozzle. By replacing the wood panel of one side of the VFDC with a plexiglass sheet it was possible to visualize the' flow pattern of smoke injected into the VFDC. This evaluation revealed that the flow field had characteristics which prevented accurate sampling with the multi-stage impactor setup used.

Tests were later conducted with a set of 3 single stage impactors used in the manner described earlier. Use of the single stage impactors did not interfere with standard VFDC operation and the operating conditions were exactly the same as that of the VFDC. The three single stage impactors were used at a flow rate of 29.7 liters/sec (63 scfm) and the corresponding 50% cut points were 42 uma, 25 uma and 13.6 uma, respectively. The measured mass median diameter (MMD) and geometric standard deviation (GSD) for GTSP, DAP, phosphate rock and white sand were 12 uma and 2.2, 17.5 uma and 1.7, 25.5 uma and 1.8 and 7.4 uma and 3.2, respectively (Figures 23 and 24). The aerosols from the fertilizer samples were mostly larger than 10 µm though, with GTSP, a significant mass fraction was less than 10 µm, and with white sand a major fraction was less than 10 µm. The 10 µm size is important because of recent regulations regarding particle emissions in the less than 10 µm size range and their possible health effects.

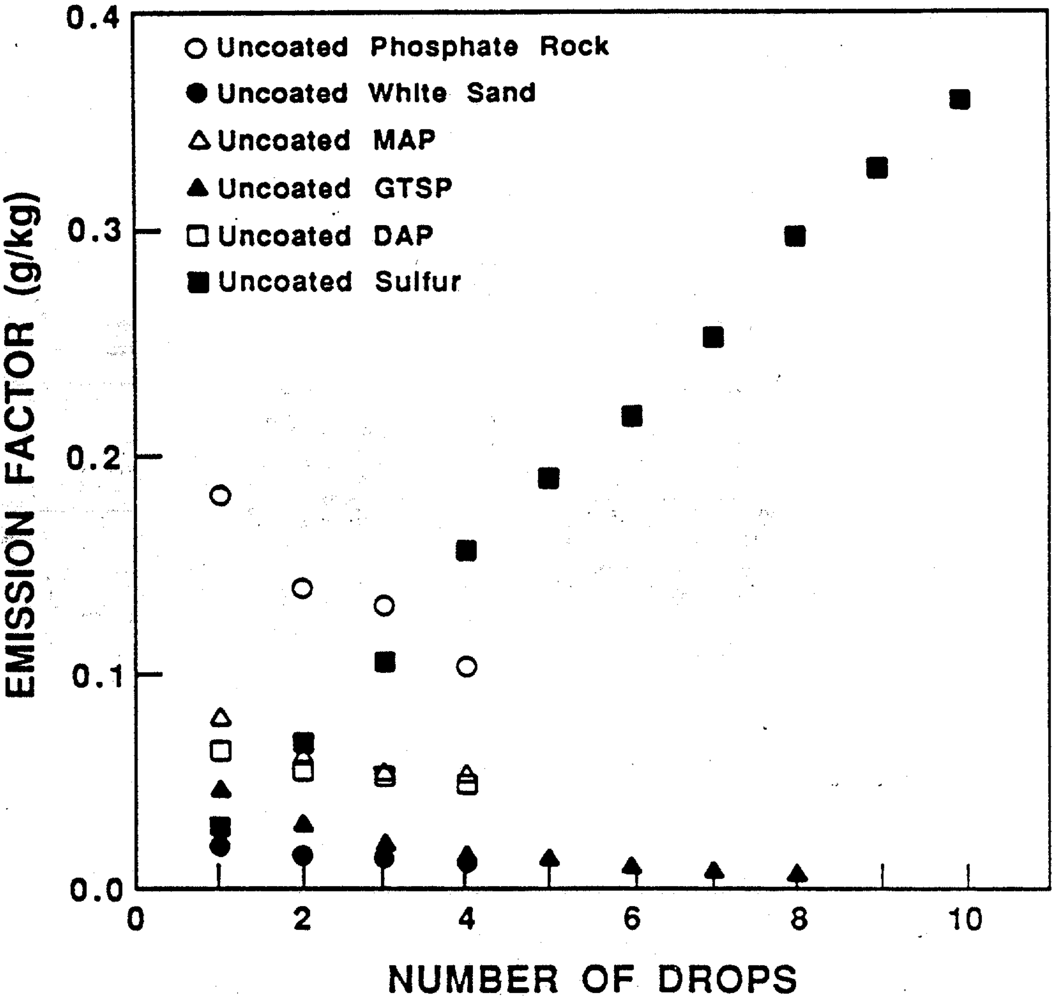


Figure 21. Effect of handling on the emission factor of various materials.

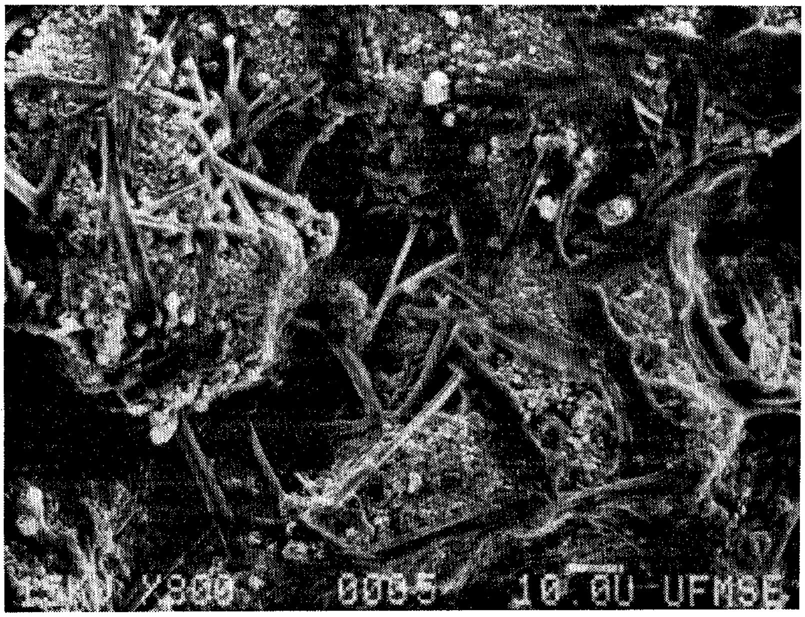


Figure 22. Photograph of crystal growth on MAP granules.

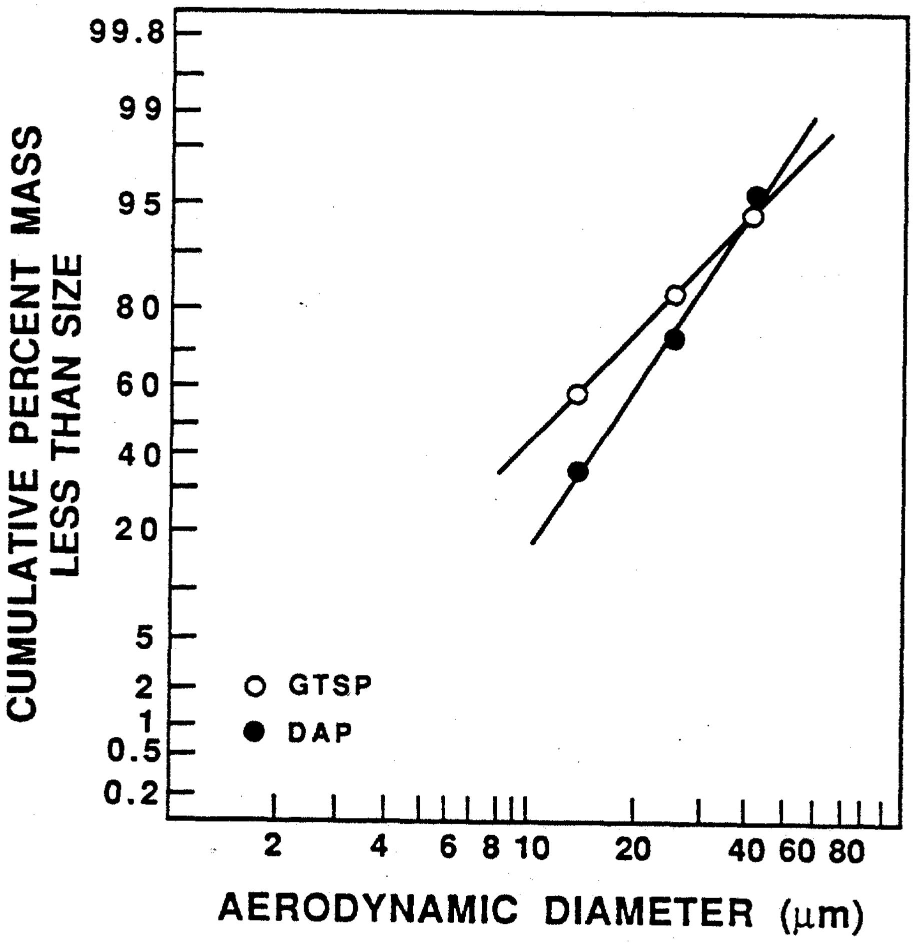


Figure 23. Size distribution of the dust emitted by handling of GTSP and DAP samples.

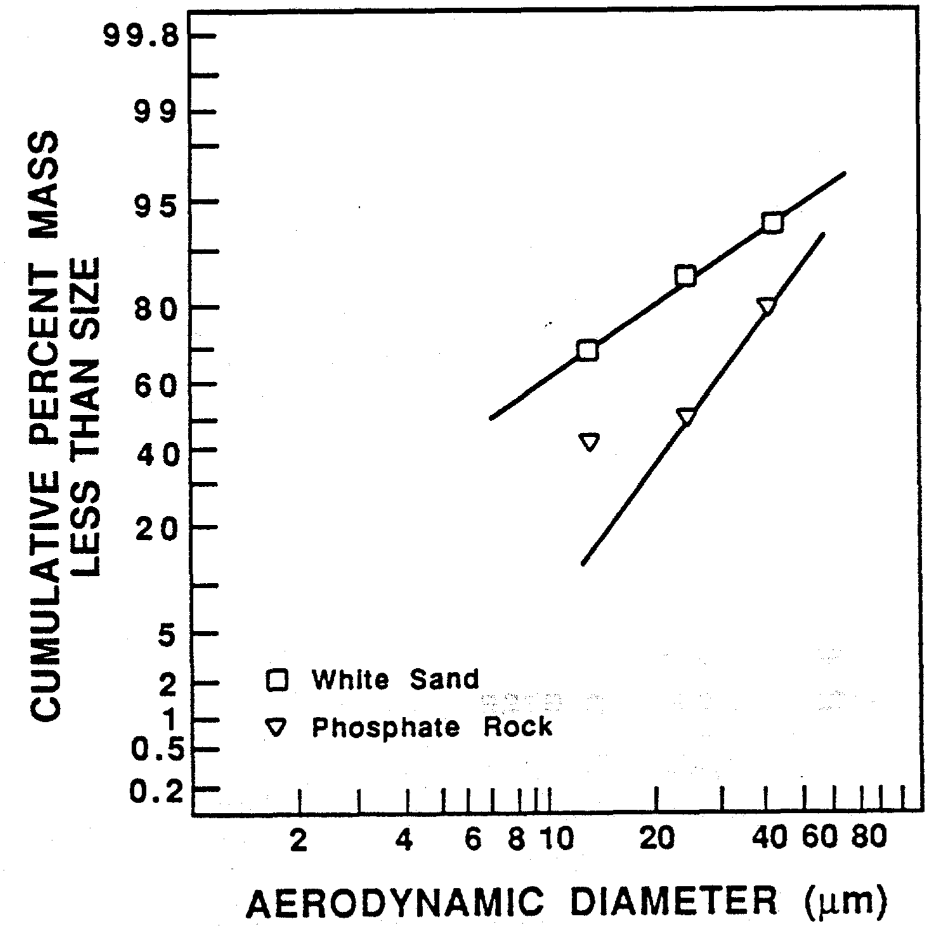


Figure 24. Size distribution of the dust emitted by handling of white sand and phosphate rock.

Product Treatments

Three principal types of fertilizer were used in the evaluation of proposed dust suppression agents. These were granular triple superphosphate (GTSP), diammonium phosphate (DAP) and monoammonium phosphate (MAP). Dust suppression agents used included oils, waxes, emulsions and other miscellaneous materials.

Oils. The kinematic viscosities of various oil blends in actual industrial use, were measured using Cannon-Fenske type glass capillary viscometers according to procedures described in ASTM method D445-82. These oils were then applied in the standard manner to GTSP samples. The coated samples were drop tested immediately and again after an aging period. In general, the test results (Table 14) reveal that for oils with kinematic viscosities in the 50 to 250 centistokes range the performance was poor. In addition, as the viscosity decreased the performance decreased. Tests were also conducted with naphthenic oils with kinematic viscosities of 105, 410 and 755 SUS, respectively. Results (Table 15) again show a definite decrease in dust release with increased kinematic viscosity, but with aging the performance was again severely degraded as manifested by the increased dust release values.

It has been stated in literature (Frick, 1977) that the dust suppression effectiveness of oils improves with increasing paraffinic content. The aniline point represents the relative paraffinic content of oils and is a commonly used measure. Paraffinic oils with aniline points in the 102°C to 121°C range were acquired from 2 manufacturers and sprayed on GTSP samples. Drop-test results (Table 16) do, indeed, show that increased aniline points lead to decreased dust release, but the performance was still average.

A number of other oils, including petroleum and vegetable oil blends, were evaluated. The results show that most of the oils tested with GTSP (Table 17) exhibited increased dust release with increasing age though some oils retained their effectiveness to a greater extent. Most of the oils tested on DAP (Table 18), on the other hand, showed low initial dust release levels and smaller increases in dust release with age.

In summary, of the oil blends tested only some had low initial dust release values (better than 10 %) and even fewer had low final dust release values when used with GTSP. With DAP all the oils tested had low dust release values and exhibited small increases in dust release with age. This product specific behavior was probably caused by differences in the interactions at the substrate oil interface leading to migration of the oil from the granule surface to the granule interior at different rates. Differences in granule porosity and oil viscosity and the corresponding differences in performance suggest that the above explanation is quite plausible. This aspect is considered again later in this chapter.

TABLE 14

Effect of the Kinematic Viscosity of Oil Blends on the Dust Release of GTSP Samples

Dust Suppressant	Sample I.D.	Kinematic Viscosity (cst)	Initial Dust Release (%)	Normalized Dust Release (%)	Final Age (days)	Final Dust Release (%)
DCA305	AN2	58	83.6	--	--	--
DCA Bell	IGTSP7	198	23.5	--	--	--
AM302EEF	AN4	204	9.4	23.7	11	61.8
AM303	B8-1	232	12.6	15.3	17	27.7

NOTE: Application Rate = 3 kg/ton.
At 20 C.
Initial Dust Release is that determined soon after application of dust suppressant.
Normalized Dust Release is that determined after an aging period of three days.

TABLE 15

Effect of the Kinematic Viscosity of Naphthenic Oils on the Dust Release of GTSP Samples

Dust Suppressant	Sample I.D.	Kinematic Viscosity (SUS)	Initial Dust Release (%)	Normalized Dust Release (%)	Final Age (days)	Final Dust Release (%)
S100	AGTSP137	105	23.2	39.0	8	65.3
S400	AGTSP138	410	11.3	23.0	8	42.5
S750	AGTSP136	755	6.4	17.8	8	36.9

NOTE: Application rate = 2 kg/ton.
At 38 C.
Initial Dust Release is that determined soon after application of dust suppressant.
Normalized Dust Release is that determined after an aging period of three days.

TABLE 16

Effect of the Aniline Point of Paraffinic Oils on the Dust Release of GTSP Samples

Dust Suppressant	Sample I.D.	Aniline Point (°C)	Initial Dust Release (%)
SP110	AGCN1	101.7	31.8
TUFLO6016	AGTSP50	107.2	32.2
SP120	AGCN2	107.8	20.3
TUFLO6026	AGTSP51	113.3	18.0
SP130	AGTSP110	115.6	14.3
TUFLO6056	AGTSP53	121.1	11.5

NOTE: Application Rate = 3.2 kg/ton.
Initial Dust Release is that determined soon after application of dust suppressant.

TABLE 17

Performance of Oil Blends as Dust Suppressants with GTSP Samples

Dust Suppressant	Sample I.D.	Application Rate (kg/ton)*	Initial Dust Release (%)	Normalized Dust Release (%)	Final Age (days)	Final Dust Release (%)
AM302EEF	GGTSP13	1.6	12.7	--	1	18.9
AM302EEF	IGTSP6	2.6	4.4	--	1	3.8
AM302EEF	AN4	3.0	9.4	23.7	11	61.8
AM303	GGTSP15	2.8	20.1	--	2	40.3
AM303	IGTSP5	3.0	7.2	8.2	4	8.5
AM303	AGTSPB81	3.0	12.6	15.3	17	27.7
DCA BELL	GGTSP14	1.6	11.0	--	--	--
DCA BELL	IGTSP7	3.0	23.5	--	--	--
TUFLOZOOO	AGTSP60	3.6	3.4	6.5	11	14.8
Carnation	AGTSP77	2.8	17.8	23.2	8	32.1
TUFL055	AGTSP52	3.4	57.5	--	--	--
ADS-197-2	AN3	4.6	31.9	--	--	--

NOTE: Initial Dust Release is that determined soon after application of the dust suppressant
Normalized Dust Release is that determined after an aging period of three days.

*Unless stated otherwise ton implies metric ton.

TABLE 18

Performance of Oil Blends as Dust Suppressants with DAP Samples

Dust Suppressant	Sample I.D.	Application Rate (kg/ton)	Initial Dust Release (%)	Normalized Dust Release (%)	Final Age (days)	Final Dust Release (%)
AM302EEF	GODAP10	1.6	8.7	--	2	5.4
AM302EEF	IMCDAP14	2.0	6.4	--	2	6.8
AM302EEF	GODAP7	3.4	4.3	3.9	10	3.1
AM303	IMCDAP15	2.6	9.3	7.2	4	6.5
AM303	GODAP11	3.2	5.5	6.2	4	6.4
AM303	GODAP5	4.4	6.6	5.7	8	4.3
DCA BELL	IMCDAP8	1.4	7.5	--	--	--
DCA BELL	GODAP2	3.1	12.5	9.6	8	4.7

NOTE: Initial Dust Release is that determined soon after application of the dust suppressant.
Normalized Dust Release is that determined after an aging of three days.

Waxes. Waxes evaluated included natural waxes such as paraffin wax, microcrystalline wax, candellila wax, carnauba wax and montan wax and many petrolatum and related waxes. Results of a preliminary qualitative evaluation are shown in Table 19 and further details on the use and properties of natural waxes are described elsewhere (Bennett, 1975). The waxes melt with varying degrees of difficulty. Paraffin, microcrystalline and candellila waxes formed coatings or films which were either flaky or powdery in nature and, for this reason, were not expected to be effective dust suppressants when used as melts. Montan wax did not melt easily and when it eventually did so, it was "tarry" and did not spray properly. Carnauba wax, though it melted easily, formed a "grainy" melt and thus an intermittant, uneven spray was produced. Petrolatum waxes, on the other hand, melted easily, sprayed easily and formed good, ductile films that adhered well to substrate materials.

Based on the qualitative evaluations, it was expected that the natural waxes would give poor results. The melting points of paraffin wax and candellila wax were 55°C and 70°C, respectively. Tests were conducted at an application rate of 2 kg/ton and, as expected, the performance was very poor. In fact, candellila wax had such poor adhesive qualities that the coated emission factor was much greater than the uncoated emission factor (measured dust release = 613%) thus suggesting that the coating itself was shedding and contributing to the overall emission. For paraffin wax the measured dust release was 72%.

Petrolatum and related waxes were the only materials, among those considered, that appeared to have good spray qualities and, thus, the potential for superior performance. A total of 11 waxes from 3 different manufacturers were evaluated. Of these Light Plasticrude and NW7098 were slack waxes while all the others were various grades of petrolatum waxes. These waxes were classified as having low, medium or high oil content based on the approximate oil content values provided by the manufacturers and some of their properties are summarized in Table 20.

Since the waxes were sprayed as melts the ease of melting was an important consideration. In general, the higher the oil content, the easier it is to melt a wax. All the petrolatums, except NW6889, melted and sprayed easily. NW6889 had the lowest oil content and the highest melting temperature and was a little more difficult to handle. However, with proper selection of spraying conditions, NW6889 was also sprayed without undue difficulty.

The effectiveness of the dust suppressant ultimately depends on the application rate. As a result, 3 different application rates, nominally 1 kg/ton, 2 kg/ton and 4 kg/ton, were used and the results are shown in Tables 21, 22 and 23, respectively. The most important factors in judging coating performance are the initial and final dust releases. Since not all the petrolatum waxes were tested after the same aging period a normalized dust release was calculated for an

TABLE 19

Qualitative Characteristics of Waxes

Type	Remarks
Paraffin Wax	1. Received in prilled form. 2. Melts easily. 3. Sprays easily. 4. Forms hard, flaky films.
Microcrystalline Wax	1. Received as a hard block. 2. Melts with some difficulty. 3. Hard to spray. 4. Forms hard, flaky film.
Candellila Wax	1. Received as a hard block. 2. Melts easily. 3. Sprays easily. 4. Forms loose, powdery film. 5. Significant shrinkage of film on cooling.
Montan Wax	1. Received as fine beads. 2. Melts with difficulty to a tarry product. 3. Could not be sprayed 4. Significant shrinkage of film on cooling.
Carnauba Wax	1. Received as flakes 2. Melts easily. 3. Sprays intermittently due to grainy texture of melt. 4. Significant shrinkage of film on cooling.
Petrolatum Wax	1. Received as "pastes" with various oil contents. 2. Melts and sprays easily. 3. Forms smooth, strong film.

TABLE 20

Physical Properties of Petrolatum and Slack Waxes

Dust Suppressant	Oil Content		Specific Gravity	Melting Point			Congealing Point		Penetration at 25°C		Viscosity at 100°C		Cost
	ASTM #	(%)	at 16 C	ASTM #	(°C)	(°C)	ASTM #	(°C)	ASTM #	units	ASTM #	SUS	($/kg)
NW6889	D721	5	--	D127	79	74	D938	68	D937	41	D445	77	0.3960
NW6364LA	D721	15	--	D127	29-41	52	D938	29	D937	100-250	D445	60	0.7755
NW7098	D721	10	--	D127	60-66	59	D938	60-66	D1321	66	D445	49-54	0.2530
NWLP	D721	15	--	D87	54-58	51	D938	54-58	D1321	51	D445	40-55	0.2090
Tech Pet F	D721	20	0.87	D127	57-66	60	D938	50-58	D937	160-190	D445	85-100	0.5830
YP2A	D721	25	0.87	D127	54-60	52	D938	46-52	D937	180-210	D445	80	0.6160
Red Vet	--	--	--	--	--	57	--	--	--	--	--	--	0.6050
Pet HM	D721	10	0.89	D127	52-66	53	D938	41-52	D937	125-175	D445	75-125	0.6600
P4523	D721	28	0.87	D127	46-57	52	--	--	D937	170-260	D445	70-115	0.6105
P4556	D721	20	0.87	D127	52-60	59	--	--	D937	130-175	D445	70-95	0.6105
P4576	D721	12	0.87	--	--	57	--	--	--	--	--	--	--

NOTE: Measured as per technique described in [Bennett, 1975].
Minimum.

TABLE 21

Performance of Petrolatum Waxes as Dust Suppressants at a Nominal Application Rate of 1 kg/ton

Dust Suppressant	Application Rate (kg/ton)	Sample I.D.	Initial Dust Release (%)	Normalized Dust Release (%)	Final Age (days)	Final Dust Release (%)	Loss Rate (%/day)
Pet HM	1.2	AGTSP73	5.3	5.6	34	9.0	0.12
NW6889	1.0	AGTSP100	3.9	3.9	46	2.3	-0.01
P4576	1.2	AGTSP74	16.5	17.5	35	28.3	0.34
Tech Pet F	1.0	AGTSP72	11.2	11.7	33	16.6	0.16
NW6364LA	1.0	AGTSP106	5.9	6.5	53	16.5	0.20
P4556	1.0	AGTSP81	11.9	13.0	35	24.4	0.36
Red Vet	1.0	AGTSP71	21.0	22.1	28	31.5	0.88
P4523	1.0	AGTSP82	12.6	14.4	35	33.9	0.61

NOTE: All samples are GTSP.
Initial Dust Release is that determined soon after application of the dust suppressant.
Normalized Dust Release is that determined after an aging period of three days.
Final age test represents the final test of the sample.

TABLE 22

Performance of Petrolatum and Slack Waxes as Dust Suppressants at a Nominal Application Rate of 2 kg/ton

Dust Suppressant	Application Rate (kg/ton)	Sample I.D.	Initial Dust Release (%)	Normalized Dust Release (%)	Final Age (days)	Final Dust Release (%)	Loss Rate (%/day)
Pet HM	2.0	AGTSP65	4.0	4.5	14	6.2	0.16
NW6889	2.0	AGTSP103	2.5	2.5	47	2.0	-0.01
NW6889	1.8	GRDAP91	6.2	6.0	75	2.0	-0.06
P4576	2.0	AGTSP115	3.4	4.1	58	17.5	0.24
Tech Pet F	2.0	AGTSP75	2.1	2.3	35	4.6	0.07
NW6364LA	2.0	AGTSP105	2.2	2.2	52	2.8	0.01
NW6364LA	2.0	GRDAP90	2.0	2.0	79	2.2	0.00
P4556	2.0	AGTSP116	4.4	4.9	63	14.7	0.16
Red Vet	2.2	AGTSP76	3.0	3.4	35	7.4	0.13
P4523	2.0	AGTSP107	4.7	5.8	58	26.9	0.38
YP2A	2.0	AGTSP59	4.8	5.5	16	8.6	0.24
NW7098	2.0	AGTSPB826	2.9	--	--	--	--
NWLP	2.0	AGTSP882	9.4	--	--	--	--

NOTE: All samples are GTSP except GRDAP91 and GRDAP90.
Initial Dust Release is that determined soon after application of the dust suppressant.
Normalized Dust Release is that determined after an aging period of three days.
Final age test represents the final test of the sample.

TABLE 23

Performance of Petrolatum Waxes as Dust Suppressants at a Nominal Application Rate of 4 kg/ton

Dust Suppressant	Application Rate (kg/ton)	Sample I.D.	Initial Dust Release (%)	Normalized Dust Release (%)	Final Age (days)	Final Dust Release (%)	Loss Rate (%/day)
Pet HM	4.2	AGTSP111	0.7	0.8	70	2.0	0.02
Tech Pet F	4.0	AGTSP112	0.9	0.9	70	1.6	0.01
NW6364LA	4.2	AGTSP104	1.0	1.0	52	1.4	0.01

NOTE: All samples are GTSP.
Initial Dust Release is that determined soon after application of the dust suppressant.
Normalized Dust Release is that determined after an aging period of three days.
Final age test represents final test of sample.

averaging period of 3 days to permit direct comparison of results from different petrolatum waxes. A loss or decay rate was also calculated and used as an indicator of the rapidity with which the performance changes. Both the above parameters were calculated assuming linear variation of dust release with age. The variation could well be non-linear, but as a first step the linear assumption provides a quick method of comparing different coatings. Thus, for screening purposes, a good coating is chosen to be one which shows a low initial and normalized dust release and a low loss rate.

Therefore, from Table 21 it can be concluded that NW6889 had the best overall effectiveness since the dust release was the smallest at 1 kg/ton. Pet HM and NW6364LA were also effective. From Tables 21, 22 and 23 it will also be observed that the loss rate, in general, decreased with increasing application rates. Because of this effect some of the coatings which performed marginally well at 1 kg/ton performed significantly better at higher application rates. NW6364LA and NW6889 were also used on DAP and again the dust releases were very low. The other petrolatum waxes will work just as well on DAP. The results show that the petrolatum waxes were excellent dust suppressants and that they provided long-term control of fugitive dust emissions.

As discussed earlier, granule fracture was not a significant factor with fertilizer granules. The wax coatings were found to effectively suppress the surface dust and multiple handlings produced continually decreasing dust emissions. With sulfur treated identically the wax was found to be just as effective (Figure 25) with the measured dust release being 3 %. More importantly, even after 10 drops the dust release did not increase thus suggesting that the wax suppressed dust emissions even though significant fracture of the substrate material was occurring.

In actual plant situations coatings are normally applied on warm product prior to transfer to storage. The fertilizer temperature in such situations is usually about 49°C. Therefore tests (Table 24) were conducted to study the effect of fertilizer temperature on dust suppressant performance. Unless specified otherwise, in all laboratory tests the dust suppressants were applied while the fertilizer sample was in the storage bag. However, for tests with warm product the fertilizer sample was transferred into 2 enameled pans so that the fertilizer sample was an inch deep in the pan and placed in a 100°C oven for 2 hours. While still in the pan the top layer was sprayed, then a new layer was created by turning over the pan contents with a spatula and sprayed again. This process was continued till the quantity required was attained. Results from the "pan coating" technique and the "bag coating" technique for product at ambient temperature were comparable. The results also indicated that product temperature affected dust suppressant performance significantly, with the lower melting petrolatum wax (NW6364LA) being affected more severely. Because of the nature of the experimental procedure, the product temperature indicated was only an approximate maximum measured at the beginning of the coating

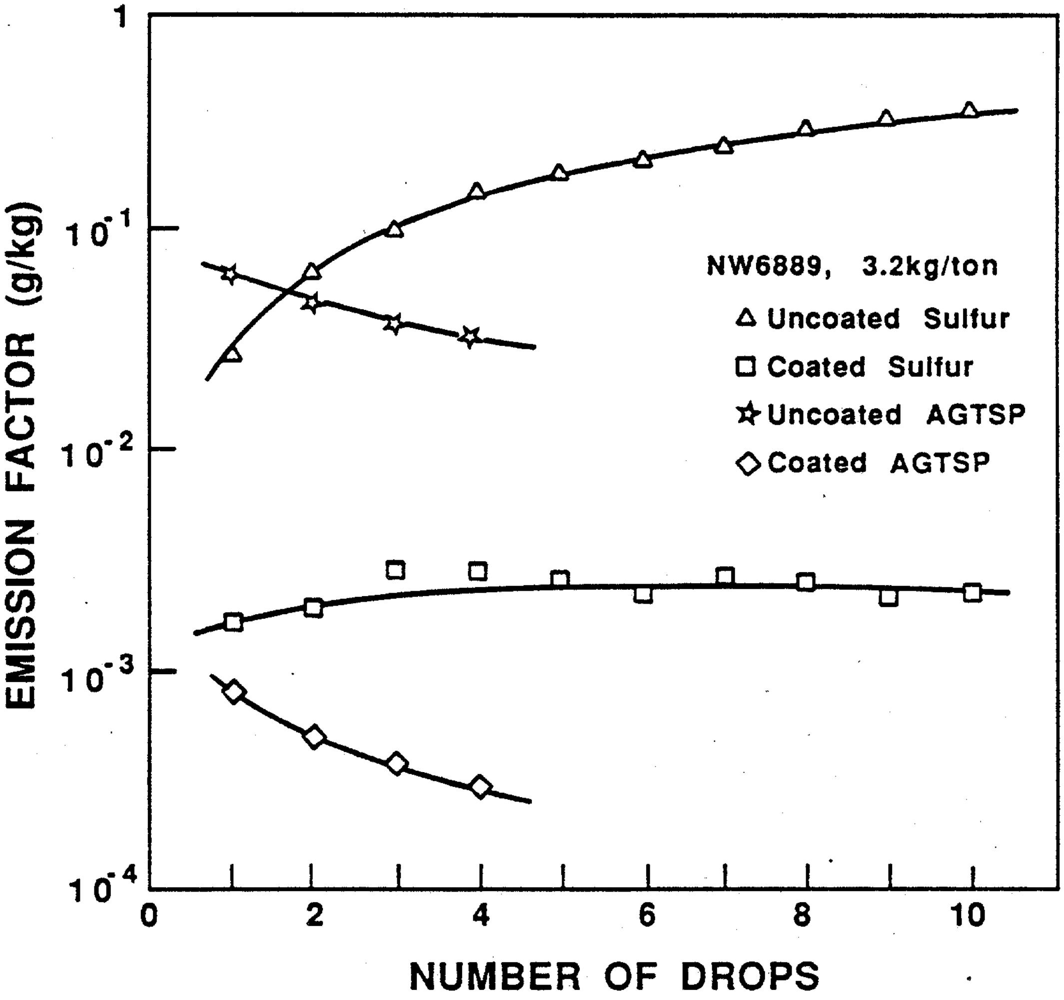


Figure 25. Effect of handling on the emission factor for coated and uncoated samples of GTSP and prilled sulfur.

TABLE 24

Effect of Fertilizer Temperature on the Performance of Petrolatum Waxes with GTSP -- Preliminary Tests

Sample I.D.	Initial Moisture Content (%)	Final Moisture Content (%)	Product Temperature (°C)	Dust Suppressant	Initial Emission Factor (g/kg)	Final Emission Factor (g/kg)	Dust Release (%)	Coating Method
AGTSP135	0.97	--	Ambient	None	0.0438	--	--	--
AGTSP134	0.96	--	Ambient	None	0.0433	--	--	--
AGTSP134	0.87	0.54	63	None	--	0.0628	--	--
AGTSP125	0.94	0.27	74	None	--	0.0684	--	--
AGTSP105	--	--	Ambient	NW6364LA	0.0405	0.0009	2.2	in bag
AGTSP103	--	--	Ambient	NW6889	0.0405	0.0010	2.5	
AGTSP140	0.96	--	Ambient	NW6364LA	0.0435	0.0029	6.7	in pans
AGTSP131	0.82	--	Ambient	NW6364LA	0.0435	0.0024	5.5	
AGTSP122	0.77	--	Ambient	NW6889	0.0435	0.0041	9.4	in pans
AGTSP121	0.81	--	Ambient	NW6889	0.0435	0.0036	8.3	
AGTSP124	0.73	0.31	78	NW6364LA	0.0656	0.0132	20.1	in pans
AGTSP123	0.97	0.13	80	NW6364LA	0.0656	0.0105	16.0	
AGTSP132	0.84	0.15	80	NW6364LA	0.0656	0.0248	36.3	
AGTSP120	0.80	0.21	66	NW6889	0.0656	0.0099	13.1	in pans
AGTSP130	0.59	0.15	66	NW6889	0.0656	0.0097	14.8	

NOTE: Initial and Final Moisture Contents are that measured before and after product heating.
Application Rate = 2 kg/ton.
For the coated samples the Initial Emission Factor indicated is that for the uncoated batch.
Samples are coated either in pans or in bags, as discussed in text.

procedure. The drop in performance was probably due to absorption of the dust suppressant into the granule interior. Since the elevated temperature chosen was higher than the wax melting temperature, the wax was still in a liquid state for a sufficient length of time to permit absorption. At ambient temperatures the fertilizer temperature was much lower than the wax melting temperature and so the wax solidified on the granule surface before significant penetration could occur. This aspect is explored further later in this chapter.

Emulsions. Some of the waxes named earlier were a little difficult to melt and spray. So, water based emulsions were considered as a means of delivering the wax to the granule surface. Water based emulsions have the advantage of raising the granule moisture content and do not need the special handling required by the melts.

The natural waxes were emulsified using a simple saponification process. The wax was first melted in a beaker and then a boiling solution of potassium hydroxide or potassium carbonate was poured into the beaker. The mixture was thoroughly stirred for a number of hours to ensure homogenization. Candellila and carnauba waxes emulsified easily while montan wax formed a dispersion rather than an emulsion. The candellila wax emulsions tended to thicken with time while the carnauba and montan wax emulsions tended to sediment with time. Emulsion stability was thus a significant problem. Emulsions with various wax concentrations were tested with GTSP and the results are presented in Table 25. As a control, tests were also conducted using an equivalent weight of water as a coating agent. Though it appeared that the emulsions had reasonable performance levels, this conclusion was misleading. In general, the dust release characteristics of fertilizer samples coated with emulsions were similar to those treated with plain water. This suggests that the water based emulsions were not a significant improvement over plain water and reinforces the importance of product moisture content. In addition, application of water subsequent to product manufacture can create caking problems.

The petrolatum waxes could not be saponified in the same fashion. Special surfactants were required to form stable emulsions and so little success was achieved. However, based on results from tests with the natural wax emulsions, it appears that emulsions may not be appropriate long term dust suppressants.

Miscellaneous Coating Agents. In addition to the coatings described earlier, other dust suppressants were evaluated and the results are shown in Table 26. Lignin, a by-product of the paper and pulp industry, has been claimed to be a good dust suppressant. However, when applied directly on GTSP, lumpy agglomerates of granules were produced and the resulting coated product had a higher emission factor than the uncoated product. The coating agent did not bind with the granule surface and was dispersed into the air by handling the coated product. When the granular product was first coated with oil and then coated with lignin, a smooth hard coat was formed and the

TABLE 25

Performance of Wax Emulsions as Dust Suppressants with GTSP Samples

Emulsion I.D.	Sample I.D.	Application Rate (kg/ton)	Initial Dust Release (%)	Normalized Dust Release (%)	Final Age (days)	Final Dust Release (%)
0.25 % Montan	AGCN11	3.0	6.1	6.3	11	6.8
0.5 % Montan	AGCN14	3.0	10.9	--	--	--
1.0 % Montan	AGCN16	3.2	10.4	--	--	--
1.0 % Montan	AGCN9	3.4	9.2	8.2	3	8.2
1.0 % Candellila	AGTSP64	3.6	14.8	15.2	13	16.5
1.0 % Candellila	AGCN10	3.0	8.3	7.1	4	6.7
5.0 % Candellila	AGCN13	3.2	18.4	12.6	3	12.6
1.0 % Carnauba	R15	2.2	13.1	14.8	10	18.9
2.5 % Carnauba	AGTSP79	3.0	17.2	21.2	9	29.2
5.0 % Carnauba	AGTSP78	3.2	17.8	20.3	9	25.4
5.0 % Carnauba	R8	3.6	10.9	11.0	10	11.1
Water	AGCN7	3.0	6.2	7.1	11	9.5
Water	AGTSP61	3.2	22.0	--	--	--
Water	AGTSP59	3.4	21.5	21.2	13	20.2

NOTE: Initial Dust Release is that determined soon after application of dust suppressant.
Normalized Dust Release is that determined after an aging period of three days.

TABLE 26

Performance of Some Miscellaneous Dust Suppressants

Dust Suppressant Type	Dust Suppressant	Application Rate (kg/ton)	Sample I.D.	Initial Dust Release (%)	Normalized Dust Release (%)	Final Age (days)	Final Dust Release (%)
Lignin + Oil	Norlig A + DCA BELL	6.2	RM6	1.9	22.9	6	43.9
Lignin + Oil	Norlig A + DCA BELL	9.0	GODAP3	3.8	4.3	8	5.1
Lignin	Norlig A	1.7	RM4	213.0	--	--	--
Hydrocarbon Polymer	DCL1803	3.0	AGTSP1	44.3	57.4	3	57.4
Hydrocarbon Polymer	DCL1803	4.0	AGTSP4	11.8	19.2	3	19.2
Oil + Surfactant	DCA BELL + Petroleum Sulfonate	3.6	AN1	3.8	28.0	7	60.3
Lignin in oil emulsion	NALCO8802	4.3	FDAP8	43.4	--	--	--
Lignin in glycol emulsion	NALCO7981	5.2	FDAP6	37.9	--	--	--

NOTE: All samples are GTSP, except GODAP and FDAP which are DAP.
Initial Dust Release is that determined soon after application of dust suppressant.
Normalized Dust Release is that determined after an aging period of three days.

resultant coated emission factor was significantly reduced. Lignin, which is in the form of a dispersion of lignin solids in an aqueous medium, spreads easily on the oil coated product. The dust release characteristics of the lignin-oil combination coating was practically undiminished with age for the DAP sample but was once again significantly reduced for the GTSP sample.

Two commercially available lignin based emulsions (NALC08802 and NALC07981) primarily used to suppress road dust were also evaluated. One was an oil based emulsion and the other was a glycol based emulsion. Both coatings performed poorly, as shown by the high initial dust release values, Another commercially available dust suppressant for road dust, Calgon DCL1803 (a hydrocarbon polymer), was also found to be ineffective in this application. Finally, addition of a petroleum sulfonate to oil to change the wetting characteristics resulted in good initial performance but poor long-term performance.

<u>Dust Release Characteristics of Treated Fertilizer.</u> A single stage impactor with a 13.6 µm cut point was used in the manner described earlier in conjunction with the vertical flow dust chamber setup. Tests were conducted to study coating, aging and handling effects on the release of particles larger than 13.6 um. A petrolatum wax (Tech Pet F) and a naphthenic oil (S100), both of which were among the poorest performers of their class, were used at an application rate of 1 kg/metric ton. The percentage by weight of particles larger than 13.6 µm, for uncoated fertilizer samples, is shown in Figure 26. In general, all four materials tested appeared to follow a similar trend in their response to handling with the "weight % > size" value stabilizing after the third drop. This suggests that the relative amounts of large and small particles did not change though the total mass did decrease steadily for these materials. The AGTSP sample produced a much larger quantity of large particles while the other three samples produced a larger quantity of small particles.

In Figure 27 the effect of aging is illustrated. The impactor and filter contributions to the total emission factor of the coated product are compared with the corresponding values for the uncoated product and represented as a percentage. For GAMAP, both the oil and wax were quite effective in controlling the large(>13.6 µm) and small(<13.6 µm) particle fractions, though with age the oil suppressed the large particle fraction less effectively. With FDAP and IGTSP, the oil exhibited decreased performance with age and this loss was not a strong function of particle size. The wax also showed a decrease in performance though the magnitude was much smaller and not particle size dependant. Therefore, the results show that the oil was not an effective dust suppressant with both FDAP and IGTSP. In addition, the loss in performance with age was more severe with oil and does not appear to be a strong function of particle size for both the coatings evaluated.

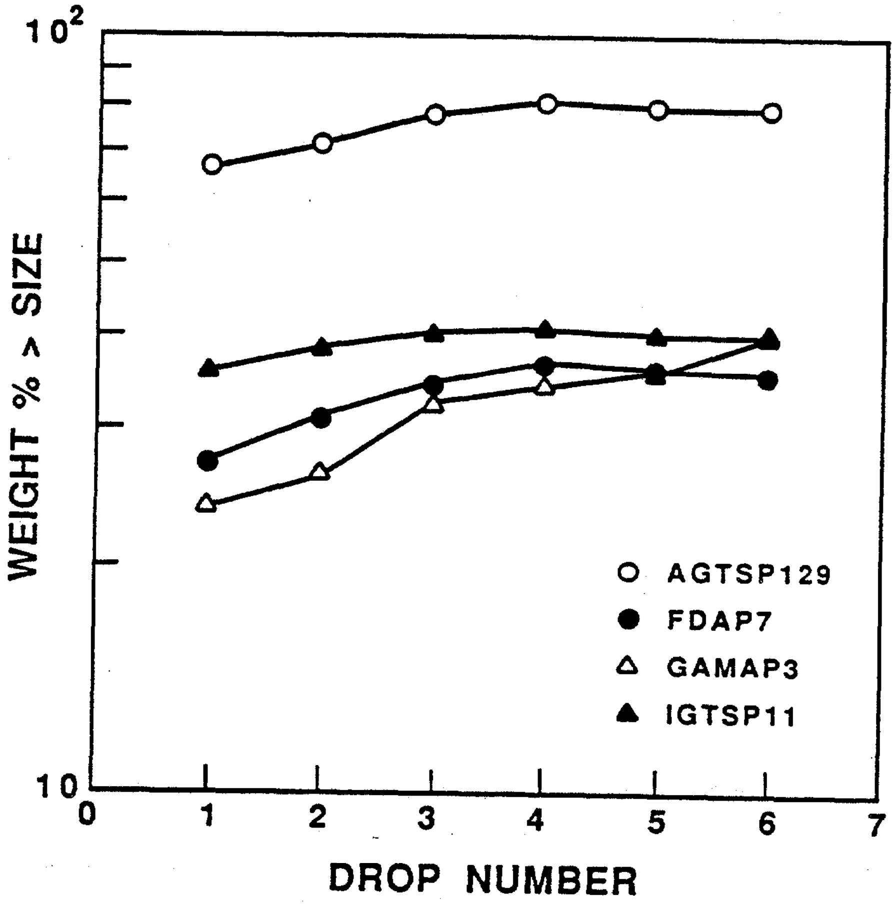


Figure 26. Effect of handling on the mass fraction of particles larger than 13.6 micrometers for uncoated fertilizer samples.

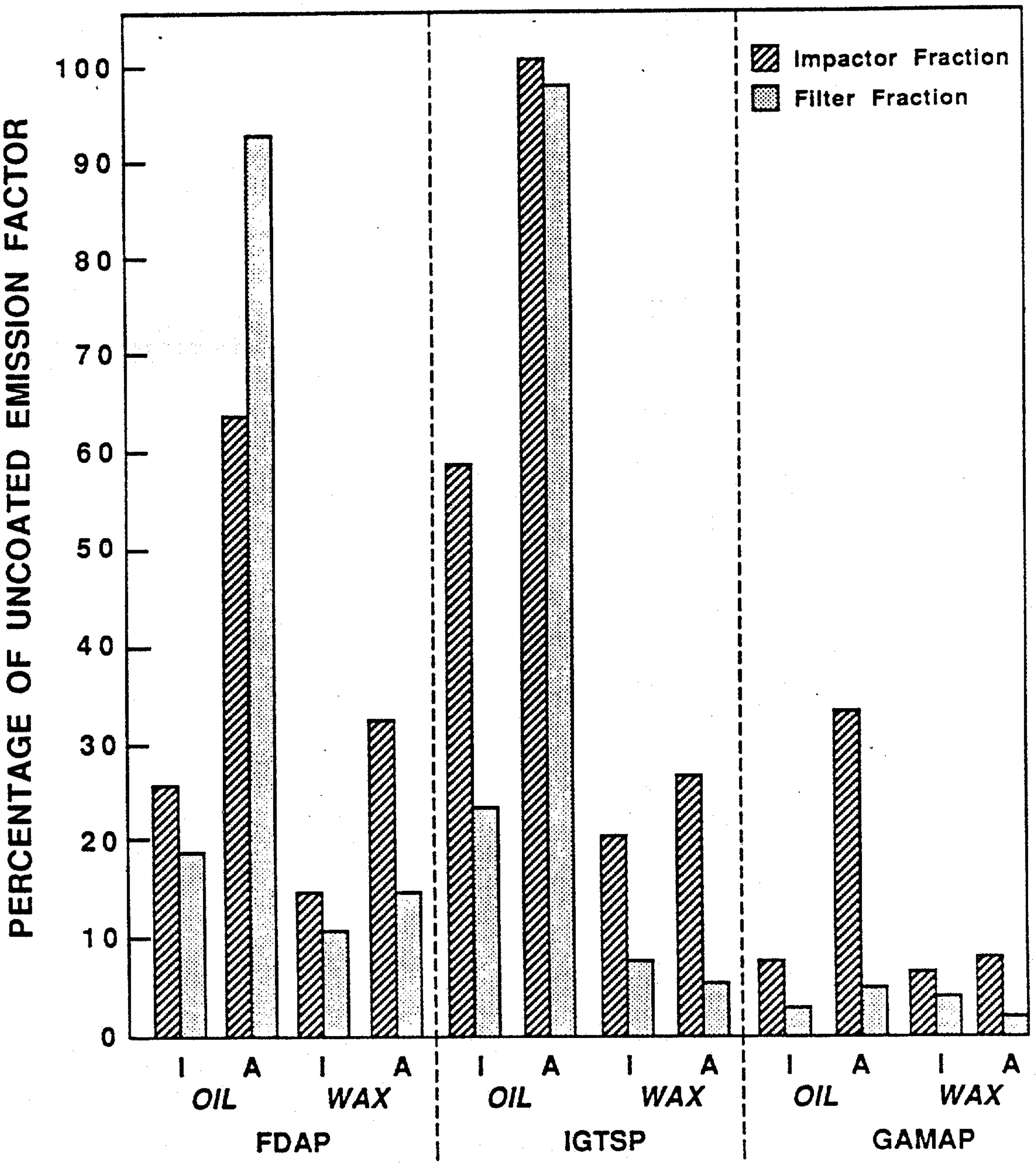


Figure 27. Relative particle release characteristics of oil and wax coated fertilizers (I-initial, A-aged).

However, as would be expected intuitively, large particles were less effectively suppressed by coating agents as compared with small particles but this difference was small for wax coatings and larger for the oil tested.

INTERMEDIATE SCALE FIELD TESTS

Five petrolatum waxes and a wood processing by-product called tall oil were further evaluated in the ISFT test setup. Once the nozzle selection and location problem was addressed there were no problems with spraying the molten petrolatum smoothly and continuously. Coating spray rates were in the 11.4 liters/hour to 26.5 liters/hour range and the fertilizer feed rates were in the 4 to 12 tons per hour range. The corresponding application rates were calculated to be in the 1 kg/ton to 3.5 kg/ton range. Results are shown in Figure 28.

As expected, the dust release was reduced with increasing application rate. Of the 5 petrolatum waxes, 4 had similar performance while the fifth, NW6364LA, appeared to perform significantly better at lower application rates. Best fit curves were fitted to the data. In general, at 2 kg/ton the dust release measured was in the 5% to 10% range. These measured values were quite similar to the results obtained from laboratory evaluations with 5-kg test samples. At an application rate of 3.4 kg/ton the dust release with the tall oil was 34 %.

Based on these results it was concluded that dust release values in the 10 % region could be attained in the field. In addition, the tests with the ISFT setup showed that handling larger quantities of wax should not be a problem if the spray system was properly designed.

FULL SCALE FIELD TESTS

Dust Suppressant and Coating Technique Evaluation

Based on the results from laboratory and intermediate scale evaluations the full scale field tests (FSFT) were undertaken. The material handling system for GTSP had a nominal rate of 250 tons/hr and the wax spray system was designed to provide application rates in the 1 kg/ton to 4 kg/ton range. The fertilizer temperature was estimated to be not more than 49°C. Both NW6364LA and Yellow Protopet 2A (YP2A) were effective in the smaller scale tests and since their melting temperatures were about 52°C they were considered ideal for this application.

In order to get an estimate of dust concentrations in the storage building (Figure 13) two high volume air samplers were operated using the standard method for ambient air sampling. The background level prior to the start of discharge in the building was about 0.5 mg/m^3. As trucks discharged their uncoated load into the receiving hopper the fertilizer was coated with oil by a "trickling" system in the

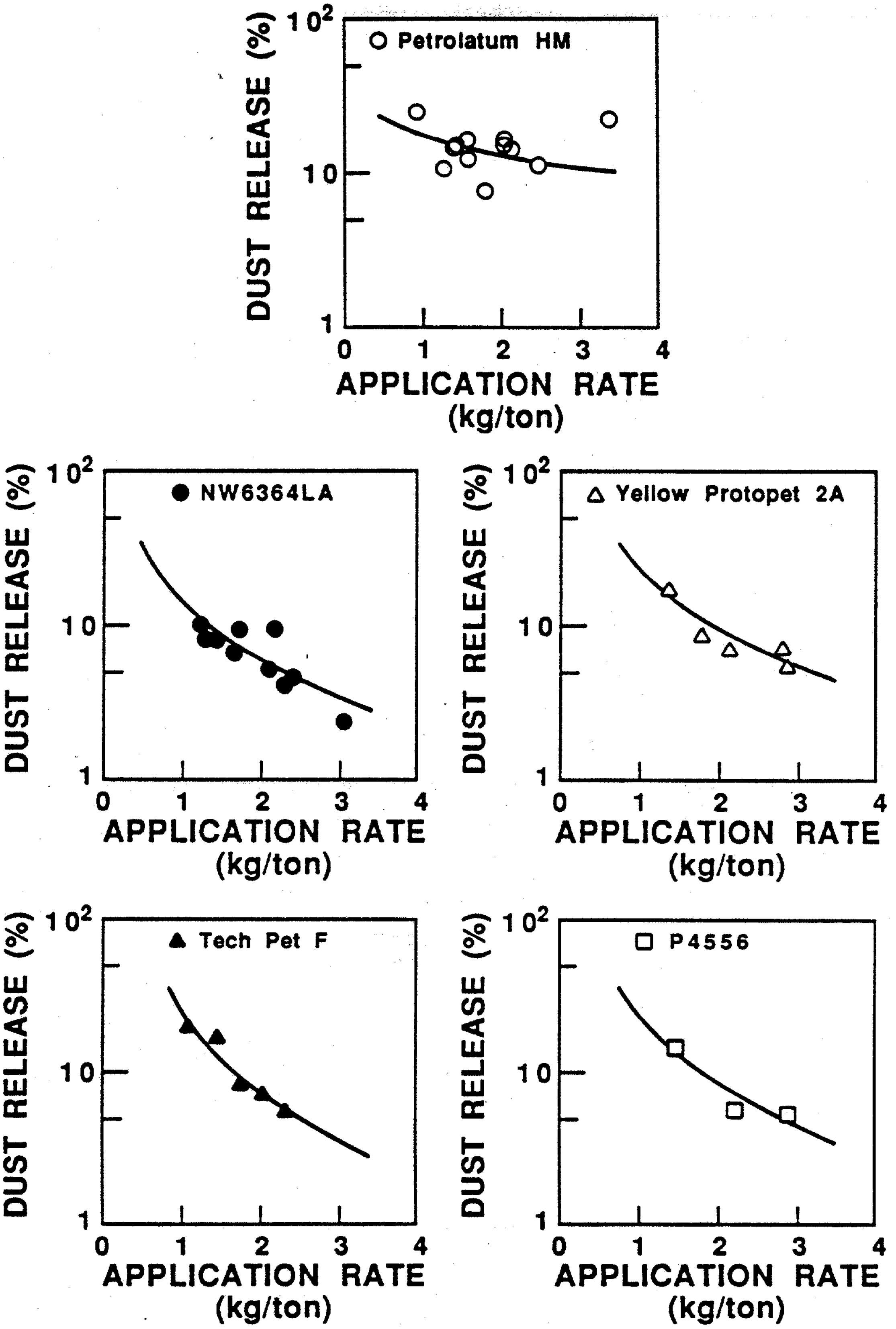


Figure 28. Performance of petrolatum waxes in intermediate scale field tests.

receiving hopper and about 2 minutes later the fertilizer was discharged through a tripper in the storage building. The dust concentration in the building when oil coated fertilizer was discharged increased to about 4.5 mg/m^3 during the duration of the test (Table 27). The measured concentration was influenced by the sampler locations. Other factors involved were the size, shape and orientation of the pile of fertilizer in the storage building, frequency of truck unloading and building ventilation by drafts caused by wind blowing through the building doors. Due to the various problems encountered during sampling it was not expected that air sampling during discharge of wax coated fertilizer would provide significant information. However, discharging uncoated fertilizer in the building significantly raises dust concentrations in the air within the building.

From the intermediate scale tests it seemed that spraying the coating agent at a transfer point would be the best course of action. Between the point of truck unloading and discharge into the building there were five transfer points. Facility constraints such as availability of space and utilities and safety considerations ruled out transfer point #2, #3 and #4. Transfer point #0 was the receiving hopper and was the location used at the facility to spray oil. Transfer point #1 was therefore chosen as the first nozzle location. Pressurized liquid nozzles were used. Three different arrangements were considered as shown in Figure 29.

Results shown in Table 28 indicate very poor coating performance. Visual observation of the coated product showed little evidence of the coating. A high volume air sampler was therefore setup just after transfer point #1 to study the problem. With arrangement 3 (Figure 29), the filter weight gain when wax was sprayed was significantly higher than that observed with uncoated fertilizer. When the oil spray at transfer point #0 was turned on the measured dust emission was reduced (Table 29). Examination of the filters under black light clearly showed significant wax deposits. When the same wax flow was pumped through 4 nozzles (arrangement 1) the measured filter weight gain was significantly reduced. This suggests that the poor results with the 2 nozzle arrangement was caused, at least in part, by excessive atomization and subsequent dispersion in the air. Air samples were also taken when oil was sprayed at transfer point #0 using the existing facility setup and when oil was sprayed at transfer point #1 using the new (UF) setup with 4 nozzles. Again filter weight gains showed similarities for both setups and the dust suppression levels were comparable. However, with NW6364LA, the dust suppression was only about 50 %, which was no better than that with oil. Transfer point #1 was the location where fertilizer was brought up from the underground receiving hopper by a drag flight conveyor. Unlike a belt to belt transfer point this arrangement discharges the fertilizer in a diffuse manner with significant turbulence. As a result, it appeared that the wax spray was dispersed in the air and little actually deposited on the granules. In addition, the turbulence caused rapid fertilizer dust and petrolatum wax build-up on the enclosure walls.

TABLE 27

Dust Concentrations within a GTSP Storage Building

Date	Test Number	Sample Location	Number of Trucks	Dust Concentration (mg/m^3)
3/20/87	1	SE	3	2.4
		NE		1.1
	2	SE	2	2.9
		NE		2.0
	3	SE	1	3.9
		NE		1.7
	4	SE	1	2.3
		NE		3.0
	5	SE	1	2.6
		NE		3.0
	6	SE	4	2.7
		NE		2.2
	7	SE	4	4.5
		NE		3.0
	8	SW	1	4.2
		NW		3.0
	9	SW	1	3.7
		NW		2.7
	10	SW	1	3.1
		NW		2.7
4/28/87	1	SW	Blank	0.42
		NW		0.49
	2	SW	1	1.86
		NW		2.52
	3	SW	1	1.56
		NW		1.99
	4	SW	1	1.03
		NW		1.79
	5	SW	1	--
		NW		30.2

TABLE 27 -- Continued.

Date	Test Number	Sample Location	Number of Trucks	Dust Concentration (mg/m^3)
4/29/87	1	SW	Blank	0.58
		NW		0.63
	2	SW	1	1.01
		NW		1.35
	3	SW	1	1.07
		NW		1.56
	4	SW	2	1.86
		NW		2.21

NOTE: Location within storage building.
Oil coated fertilizer unless stated otherwise.
Uncoated ferilizer.

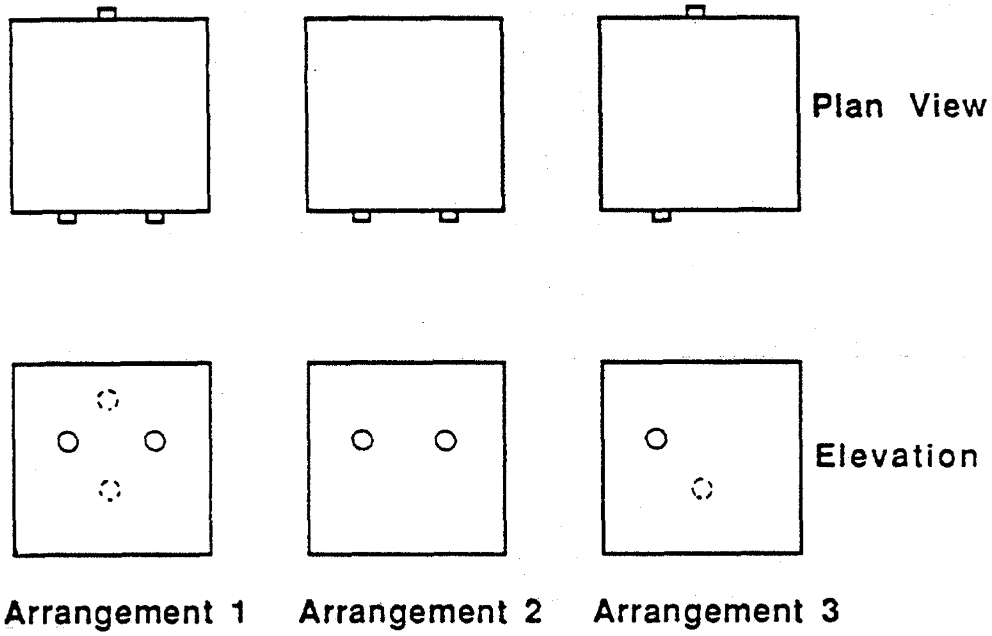


Figure 29. Nozzle arrangements at transfer point #1.

TABLE 28

Summary of Full Scale Field Test Results with GTSP

Spray Location	Nozzle Type	Dust Suppressant	Application Rate (kg/ton)	Uncoated		Coated		Dust Release (%)
				Sample Location	E.F. (g/kg)	Sample Location	E.F. (g/kg)	
At TP1	4-HFMA Opposing	NW6364LA	2.6	Belt after TP1	0.0485	Belt after TP1	0.0466	96.0
At TP1	2-HFMA Same Side	NW6364LA	2.4	Belt after TP1	0.0484	Belt after TP1	0.0527	--
At TP1	2-HFMA Opposing	NW6364LA	2.4	Belt after TP1	0.0349	Belt after TP1	0.0933	--
At TP1	4-HFMA Opposing	NW6364LA	2.6	Belt after TP1	0.0427	Belt after TP1	0.0221	51.8
At TP0	Existing	Oil	3.5	Belt after TP1	0.0677	Belt after TP1	0.0341	50.4
At TP1	4-HFMA Opposing	Oil	2.6	Belt after TP1	0.0538	Belt after TP1	0.0260	48.3
At TP1	2-HFMA 2-HFMA on Belt	YP2A	2.5	Belt after TP2	0.0567	Belt after TP2	0.0105	18.5
At TP1	2-HFMA 2-HFMA on Belt	YP2A	3.9	Belt after TP2	0.0567	Belt after TP2	0.0032	5.6
Belt after TP1	4-HFMA	YP2A	2.6	Belt after TP2	0.0487	Belt after TP2	0.0028	5.7
Belt after TP1	4-HFMA	YP2A	3.9	Belt after TP2	0.0487	Belt after TP2	0.0014	2.9
Belt after TP1	4-LFMA	YP2A	1.7	Belt after TP2	0.0260	Belt after TP2 after TP3	0.0121 0.0226	46.5 86.9
Belt after TP1	2-MFWA	YP2A	2.5	Belt after TP2	0.0279	Belt after TP2 after TP3	0.0043 0.0143	15.4 51.3
Belt after TP1	2-MFWA	YP2A	2.5	Belt after TP2	0.0245	Belt after TP2 after TP3	-- 0.0114	-- 46.5
Belt after TP1	4-HFMA	YP2A	1.7	Belt after TP2	0.0353	Belt after TP2 after TP3	0.0234 0.0300	66.3 85.0
Belt after TP1	4-HFMA	YP2A	2.6	Belt after TP2	0.0352	Belt after TP2 after TP3	0.0038 0.0153	10.8 43.5
Belt after TP1	4-MFWA with mixer	YP2A	2.6	Belt after TP2	0.0460	Belt after TP1 after TP2 after TP3	0.0186 0.0227 0.0305	40.4 49.3 66.3

TABLE 28 -- Continued.

Spray Location	Nozzle Type	Dust Suppressant	Application Rate (kg/ton)	Uncoated		Coated		Dust Release (%)
				Sample Location	E.F. (g/kg)	Sample Location	E.F. (g/kg)	
At TPO	Existing without mixer	Oil	3.5	Truck	0.0620	Belt after TP1	0.0260	41.9
						after TP2	0.0125	20.2
						after TP3	0.0122	19.7
At TPO	Existing with mixer	Oil	3.5	Truck	0.0440	Belt after TP1	0.0177	40.2
						after TP2	0.0135	30.7
						after TP3	0.0071	16.1
Belt after TP1	4-HFMA with mixer	YP2A	2.6	Belt after TP2	0.0369	Belt after TP1	0.0296	80.2
						after TP2	0.0252	68.3
						after TP3	0.0284	77.0
Belt after TP1	4-HFMA without mixer	YP2A	2.6	Belt after TP2	0.0450	Belt after TP1	0.0152	33.8
						after TP2	0.0185	41.1
						after TP3	0.0215	47.8
Belt after TP1	4-HFMA with mixer	YP2A	2.6	Belt after TP2	0.0456	Belt after TP1	0.0164	36.0
						after TP2	0.0139	30.5
						after TP3	0.0203	44.5
Belt after TP1	3-HFMA with mixer	YP2A	2.3	Belt after TP2	0.0452	Belt after TP1	0.0241	54.0
						after TP2	0.0218	48.2
						after TP3	0.0252	55.8
Belt after TP1	4-HFMA with mixer	NW6364LA	2.6	Belt after TP2	0.0390	Belt after TP3	0.0156	40.0
						at TP4	0.0126	32.3
Belt after TP1	4-HFMA with mixer	NW6364LA	3.6	Belt after TP2	0.0451	Belt after TP3	0.0146	32.4
						at TP4	0.0139	30.8
Belt after TP1	4-HFMA with mixer	NW6364LA	2.6	Belt after TP2	0.0462	Belt after TP3	0.0173	37.4
						at TP4	0.0194	42.0
Belt after TP1	4-HFMA without mixer	NW6364LA	2.6	Belt after TP2	0.0504	Belt after TP3	0.0171	33.9
						at TP4	0.0196	38.9

TABLE 28 -- Continued.

Spray Location	Nozzle Type	Dust Suppressant	Application Rate (kg/ton)	Uncoated		Coated		Dust Release (%)
				Sample Location	E.F. (g/kg)	Sample Location	E.F. (g/kg)	
At TP0	Existing with mixer	Oil	4.3	Belt after TP2	0.0261	Belt after TP3	0.0183	70.1
						at TP4	0.0158	60.5
At TP0	Existing without mixer	Oil	4.3	Belt after TP2	0.0242	Belt after TP3	0.0169	69.8
						at TP4	0.0125	51.7
At TP0	Existing without mixer	Oil	4.3	Belt after TP2	0.0772	Belt after TP3	0.0180	23.3
						at TP4	0.0247	32.0
At TP0	4-HFNA without mixer	NW6364LA	3.5	Belt after TP2	0.0379	Belt after TP3	0.0095	24.9
						at TP4	0.0124	32.8
At TP0	4-HFNA without mixer	NW6364LA	3.5	Belt after TP2	0.0652	Belt after TP3	0.0190	29.2
						at TP4	0.0152	23.3
At TP0	4-HFNA without mixer	NW6364LA	3.5	Belt after TP2	0.0425	Belt after TP3	0.0135	31.7
						at TP4	0.0133	31.2

NOTE: TP0 - Transfer Point #0 ; TP1 - Transfer Point #1.
HFMA - High Flow Medium Angle (Spraying Systems #1/4TT-9508)
LFMA - Low Flow Medium Angle (Spraying Systems #1/4TT-9504)
MFWA - Maximum Flow Wide Angle (Spraying Systems #1/4TT-11015)
HFNA - High Flow Narrow Angle (Spraying Systems #1/4TT-730770)
TP2 - Transfer Point #2.

TABLE 29

Emission Concentrations Measured after Transfer Point #1

Test Number	Truck Number	Nozzle Arrangement	Dust Suppressant	Application Rate (kg/ton)	Filter Weight Gain (g)
1	1	--	None	--	0.7605
2		3	NW6364LA	2.4	3.0089
3		Existing	Fleetwing Oil	3.8	0.4216
4	2	--	None	--	0.7805
5		1	NW6364LA	2.6	0.5585
6	3	--	None	--	3.7483
7		Existing	Fleetwing Oil	3.8	1.7144
8	4	--	None	--	4.5817
9		1	Fleetwing Oil	3.2	2.6413

NOTE: Arrangements shown in Figure 29.

In order to better distribute the coating agent 2 nozzles were installed at transfer point #1 in arrangement 3 as shown in Figure 29 and 2 more were installed over the axis of the belt conveyor just after transfer point #1. Since 2 of the nozzles were spraying on the top surface of the bead of fertilizer on the belt, samples were collected off the belt after transfer point #2. At 2.5 kg/ton the result (Table 28) seems significantly improved compared with results described earlier and at 3.9 kg/ton it was even better. When all four nozzles were located along the belt axis results were very good. However, because of the design of the material handling system, one transfer between point of coating and point of sample was found to be insufficient with regard to material mixing. Therefore, the results of some of the past tests were probably skewed.

A study was made of product variability. For a particular truck, ten 5 kg samples were collected about 20 to 30 seconds apart and a 19 liter bucket was also filled a little at a time over the period of discharge of the truck. The bucket sample represents an average sample and the average emission factor of 0.0296 g/kg had a deviation of 2.5% from the 2 individual emission factors (Table 30). The emission factors for the instantaneous samples were between 66% and 115% of the average value, though 6 out of 10 samples were between 90 % and 105 % of the average. Thus, there were small but significant differences in the product as discharged by the truck.

Similar tests were done with the existing oil spray setup operating and samples being taken off the belt after transfer point #1. The deviation of the average value was about 5 %. The variability of the instantaneous emission factor was much higher (Table 31) but the average of the instantaneous values was within 5% of the average sample. Samples taken simultaneously at the truck and off the belt after transfer point #1 with no oil spray, again showed significant variability though the samples off the belt were much worse. Because of the action of the drag flight conveyor the same fertilizer appeared to be significantly dustier when oil was not applied (Table 32). These tests show that the sampling procedure should be carefully planned so as not to unfairly skew the evaluation of dust suppressants.

Four high flow, medium angle (HFMA) nozzles were used again at an application rate of 1.7 kg/ton and 2.6 kg/ton and as expected the performance increased with application rate (Table 28). The uncoated samples were collected at transfer point #2 in 2 stages, before and after the wax spray so that a reasonable, average, uncoated emission factor could be determined. The coated samples were taken a scoop at a time at both transfer point #2 and #3. There were significant differences in the measured dust release at the two sample locations with that measured at transfer point #2 being generally lower because of insufficient product mixing and sampling bias. At 1.7 kg/ton whether the HFMA nozzles or the low flow, medium angle nozzles were used was not important and in both cases the dust release was very high. With the HFMA nozzles, raising the wax feed rate to 2.6 kg/ton

TABLE 30

Variability of Dust Emissions from Uncoated GTSP Sampled at Truck Discharge

Sample Number	Sample Type	Emission Factor (g/kg)	Average (g/kg)	Variability (%)
1	I	0.0279		94.3
2	I	0.0287		97.0
3	I	0.0299		101.0
4	I	0.0267		90.2
5	I	0.0239	0.0276	80.7
6	I	0.0283		95.6
7	I	0.0341		115.2
8	I	0.0261		88.2
9	I	0.0197		66.6
10	I	0.0305		103.0
11	A	0.0302	0.0296	--
12	A	0.0289		--

NOTE: "I" are instantaneous 5 kilogram samples collected in about 10 seconds, 30 seconds apart during truck discharge. "A" are 5 kilogram samples made from product collected in a 5 gallon bucket a scoop at a time during truck discharge.

TABLE 31

Variability of Dust Emissions from Oil Coated GTSP Sampled from Belt after Transfer Point #1

Sample Number	Sample Type	Emission Factor (g/kg)	Average (g/kg)	Variability (%)
1	I	0.0159	0.0103	162.2
2	I	0.0087		88.8
3	I	0.0178		181.6
4	I	0.0066		67.3
5	I	0.0076		77.6
6	I	0.0072		73.5
7	I	0.0138		140.8
8	I	0.0044		44.9
9	A	0.0103	0.0098	--
10	A	0.0093		--

NOTE: "I" are instantaneous 5 kilogram samples collected in about 10 seconds, 45 seconds apart during truck discharge. "A" are 5 kilogram samples made from product collected in a 5 gallon bucket a scoop at

TABLE 32

Variability of Dust Emissions from Uncoated GTSP Sampled Simultaneously at Truck Discharge and from Belt after Transfer Point #1

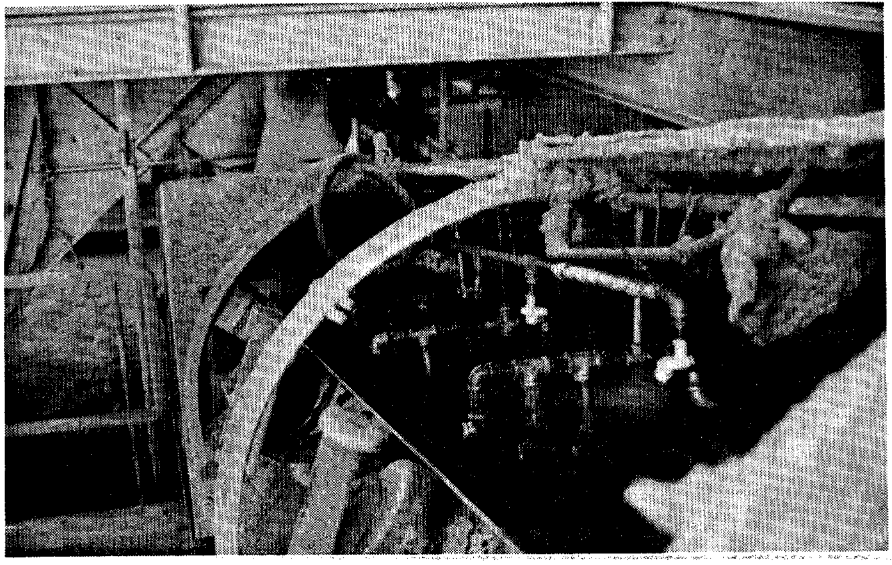
Sample Number	Sample Type	Emission Factor Truck (g/kg)	Emission Factor TP1 (g/kg)	Average Truck (g/kg)	Average TP1 (g/kg)	Variability Truck (%)	Variability TP1 (%)
1	I	0.0308	0.1314	0.0234	0.0935	150.2	104.0
2	I	0.0249	0.1288			121.5	101.9
3	I	0.0217	0.0707			105.9	55.9
4	I	0.0207	0.0631			101.0	49.9
5	I	0.0189	0.1314			92.2	104.0
6	I	--	0.0714			--	56.5
7	I	--	0.0579			--	45.9
8	A	0.0213	0.1231	0.0205	0.1264	--	--
9	A	0.0196	0.1296			--	--

NOTE: "I" are instantaneous 5 kilogram samples collected in about 1 seconds, 1 minute apart during truck discharge period. "A" are average 5 kilogram samples made from product collected in a 5 gallon bucket a scoop at a time during truck discharge.
Samples taken at truck discharge.
Samples taken from belt just past transfer point #1.

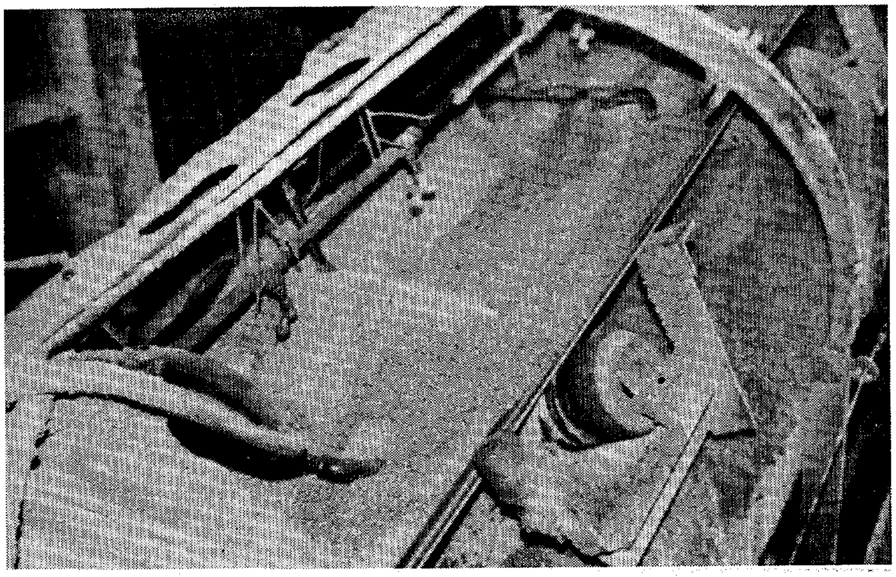
raised the nozzle operating pressure. Adding the additional wax cut the dust release in half but this was still too high. With the HFMA nozzles, operating at 2.6 kg/ton the spread did not completely cover the top surface of the fertilizer bead on the belt. So, 2 nozzles of higher capacity and wider spray angle (MFWA) were used so as to completely cover the top layer. The improvement in initial distribution of the wax, if any, did not significantly change the dust release. Installation of a plough type arrangement to introduce some mixing of the coated product on the belt also did not provide significant improvement.

The nozzles placed along the belt, axis were about 22.5 cm from the fertilizer surface so that the top layer was completely covered. At this condition the petrolatum wax was still in the form of a liquid sheet to ensure that a maximum amount would be deposited on the fertilizer. Since the dust release levels were still too high and because the coating still appeared poorly distributed a bank of mixers, as shown in Figure 30, was installed so as to present new granule surface to the spray. When only 3 nozzles were used one extra product turnover occurred because of the fourth bank of the mixer whereas, when 4 nozzles were used, after the final mixing the ensuing surface layer was given an extra coating. Tests without and with the mixer revealed no significant differences (Table 28). Samples taken at transfer point #3 and #4 did not reveal any major differences. Uncoated samples were taken simultaneously at transfer point #2 and #4 and the measured emission factors for uncoated product were found to be within 5%. Therefore, collecting uncoated and coated product at different locations did not affect the quality of the data. Data suggests that by the time the product passed transfer point #3 product mixing had played a significant role in damping out variabilities. By raising the feed rate to 3.6 kg/ton the dust release was improved to about 30 %. Thus, raising the feed rate from 1.7 kg/ton to 2.6 kg/ton decreased the dust release from about 85 % to about 40 % and raising the feed rate to 3.6 kg/ton only decreased the dust release to about 30%. Visual observation of the coated product indicated that the mixers and extra product transfers up to transfer point #4 had the effect of improving the distribution of the petrolatum wax throughout the product because of the more even coloration of the fertilizer. However, the fertilizer granules did not look as dark as granules of the same product coated in the laboratory. This difference in color contrast suggests that less wax was on the granule surface.

Finally, tests were conducted by spraying the petrolatum wax at the spray location currently used to spray oil. Four nozzles were installed within the receiving hopper. Because of the close confines of the hopper and to prevent loss of wax on hopper and drag flight surfaces high flow, narrow angle (HFNA) nozzles, which have a narrower spread, were used. At 3.6 kg/ton the average dust release for 3 successive runs was again about 30 % and this was comparable with the dust release measured when oil was sprayed with the existing setup and with results of earlier tests where the petrolatum wax was sprayed on the belt after transfer point #1.



(a)



(b)

Figure 30. Details of mixing technique.
(a) photograph of mixer for product on the belt.
(b) photograph of mixing action.

When results of these tests are compared with that from laboratory and intermediate scale field tests, it is obvious that coating performance is significantly reduced in field use. The coating agents used in the full scale field tests were NW6364LA and YP2A both of which have melting temperatures of about 52°C. The fertilizer used was the same in all the tests. The major difference was that in the laboratory and intermediate scale tests the fertilizer was at ambient temperature while the fertilizer in the full scale tests was at an elevated temperature of between 49°C and 77°C, with 60°C to 77°C being the most frequent temperature range. The temperature of fertilizer delivered by a number of trucks was measured and, as shown in Figure 31, it was quite variable, It was also observed that there was little change in product temperature between the truck discharge and transfer point #4. The temperature of two buckets of coated fertilizer was measured as a function of time (Figure 32(a)) and was found to change very slowly and, as shown in Figure 32(b), after more than five hours fertilizer temperatures greater than 49°C were observed for product stored in buckets. Because of the high initial temperature and slow cooling of the fertilizer in sample buckets, the relatively low melting temperature of the waxes causes them to behave as oils i.e., they do not harden on the granule surface rapidly. As a result, the wax was susceptible to capillary action and penetration into the granule interior leading to increased dust release. Higher melting waxes or lower fertilizer temperatures could combat this problem. However, since the pump selected for the field spray system was recommended for use with liquids at less than 85°C the higher melting wax, NW6889, was not suitable for pumping with the existing system.

Therefore, the full scale field tests demonstrated that the petrolatum waxes could be easily handled and pumped in larger quantities. The results obtained were comparable with those observed with the oil currently used at the test facility but were not as good as that obtained with the same petrolatum waxes in laboratory and intermediate scale field tests. The initial distribution of the wax did not seem to be a major factor but fertilizer temperature did influence coating performance significantly. This factor is further discussed in the next section.

Further Experiments Pertaining to FSFT Results

As discussed earlier, the fertilizer used in the full scale field tests was at an elevated temperature of between 49°C and 77°C. Once the coated samples were collected in buckets and brought back to the laboratory, measurement of temperature showed that the heat loss from the fertilizer while in the bucket was slow. Because of the fact that the dust suppression effectiveness of the selected petrolatum waxes in full scale field tests was not as high as expected, the combined effect of aging and fertilizer temperature was implicated. In addition, the effect of mixing on the distribution of the petrolatum wax was not clearly understood.

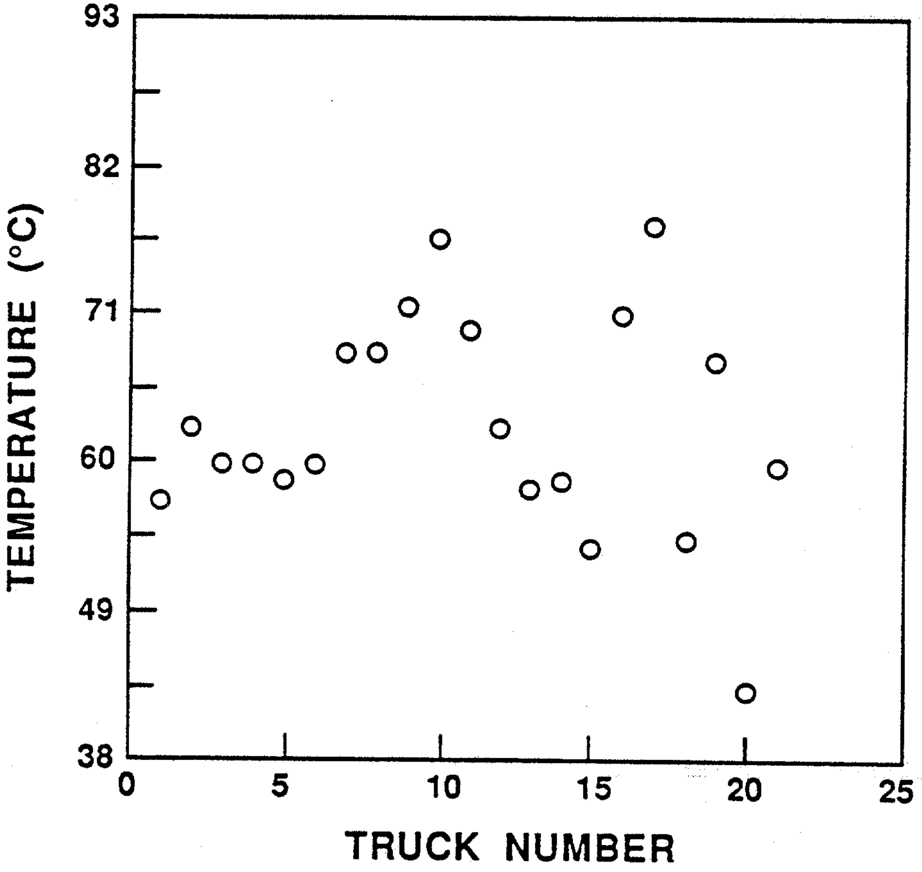


Figure 31. Variation of fertilizer temperature as discharged from a number of trucks.

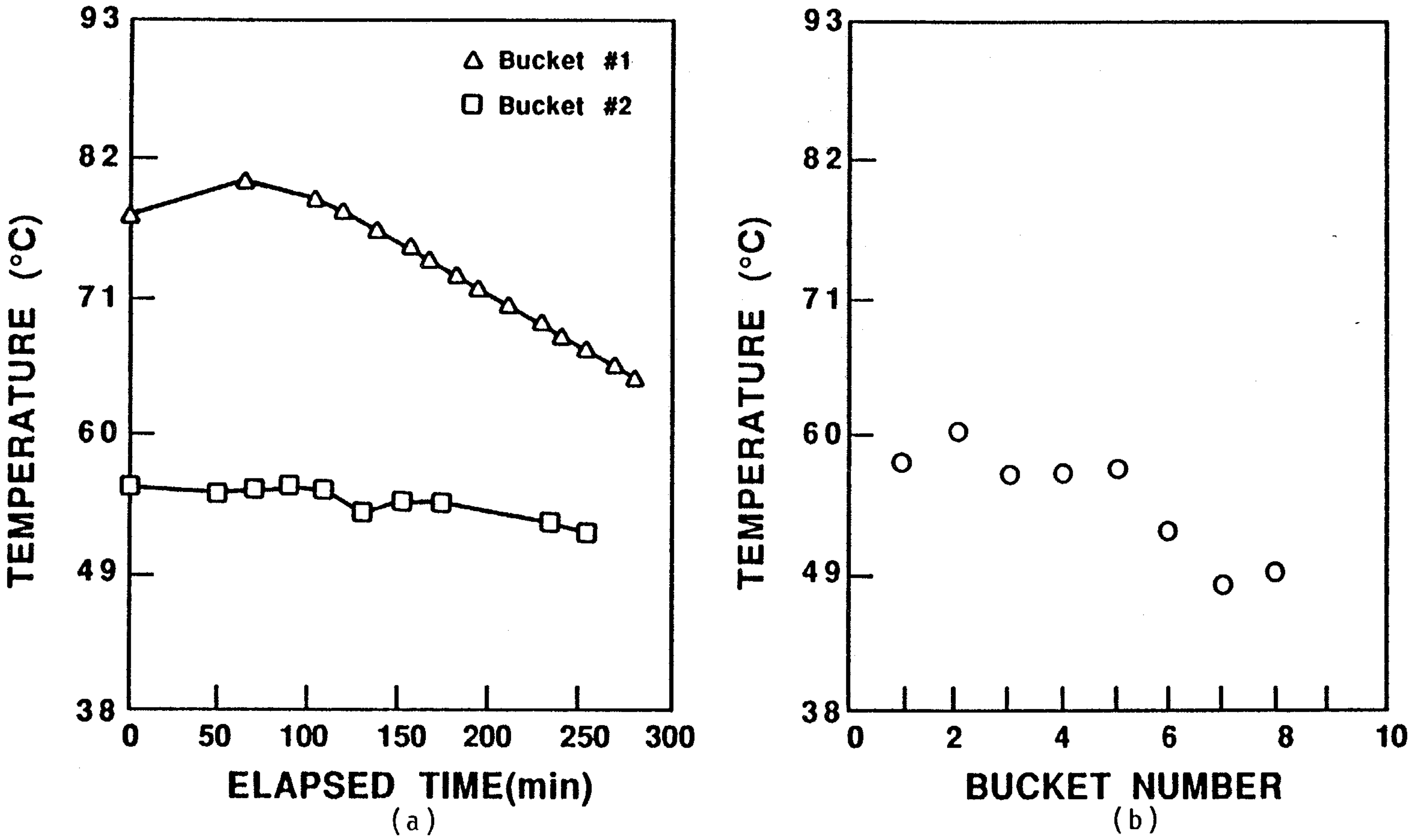


Figure 32. Temperature of fertilizer samples as a function of time.
(a) heat loss of GTSP samples over a period of time.
(b) temperature of GTSP samples five hours after collection in five gallon buckets.

In order to establish the effect of mixing on the distribution of the petrolatum waxes a number of test samples were prepared and tested in the standard manner. Twenty percent of a 5-kg sample was separated and coated with 10 grams of the petrolatum wax, an application rate of 2 kg/ton, using the procedure described earlier. The remaining uncoated portion (80%) of the sample was then mixed in the required number of times and the total sample was then "drop tested" in the standard manner. The mixing procedure was carried out in square bottomed plastic bags with one "mix" being one to and fro motion of the bag contents along the bag axis. Results shown in Figure 33 emphasize the significant effect of mixing on dust release. The fertilizer was at ambient temperature and NW6364LA, a soft wax, and NW6889, a harder wax, both produced a rapid decrease in dust release with increased mixing though the softer wax showed a faster response, as expected. Thus, though the coating was poorly distributed initially, the distribution was significantly improved by mixing as evidenced by the decreased dust release.

Tests were also conducted where the initial distribution of the coating agent was varied. Initial distributions of 20 %, 40 % and 100 % were considered and the samples were mixed 60 times. For both NW6364LA and NW6889 the initial distribution did not make a significant difference as long as moderate mixing was carried out (Figure 34(a)). The individual differences between the performance of the two waxes can be attributed to the differences in their response to a fixed number of “mixes" as discussed earlier. Similar tests (Figure 34(b), 34(c) and 34(d)) with Pet HM and P4556, petrolatum waxes of intermediate hardness, and AM303, an oil blend, showed similar results except that the oil exhibited comparatively poorer performance overall and, as expected, the lower application rate resulted in poorer performance. From these results it is clear that good mixing can overcome poor initial coating distribution and wax hardness does not significantly influence the outcome. Now, if the fertilizer temperature were higher, NW6889 would soften and distribute more easily and could be expected to perform better.

In an initial series of experiments (Table 33) with NW6364LA, 5 kilogram test samples of AGTSP were transferred to enameled pans and heated in an oven set at 105°C. The average fertilizer temperature was determined by measuring the temperature of the product in the pan using a thermocouple at 9 different locations. Once the required temperature was reached the pans were placed on a hot plate and then the top layer of fertilizer in the pan was repeatedly sprayed with the coating agent till about 10 grams of wax was added. At this point the fertilizer was transferred from the pan to the plastic storage bag and mixed 100 times. After cooling, these samples were tested. Results in Table 33 show a slightly increasing trend suggesting that dust release does increase with temperature. However, the dust release was still only about half as much as that measured in the full scale field tests. But, because of the nature of the test procedure, primarily the mixing process, the fertilizer cools quite rapidly. Therefore, the petrolatum is exposed to detrimental temperatures for only a short

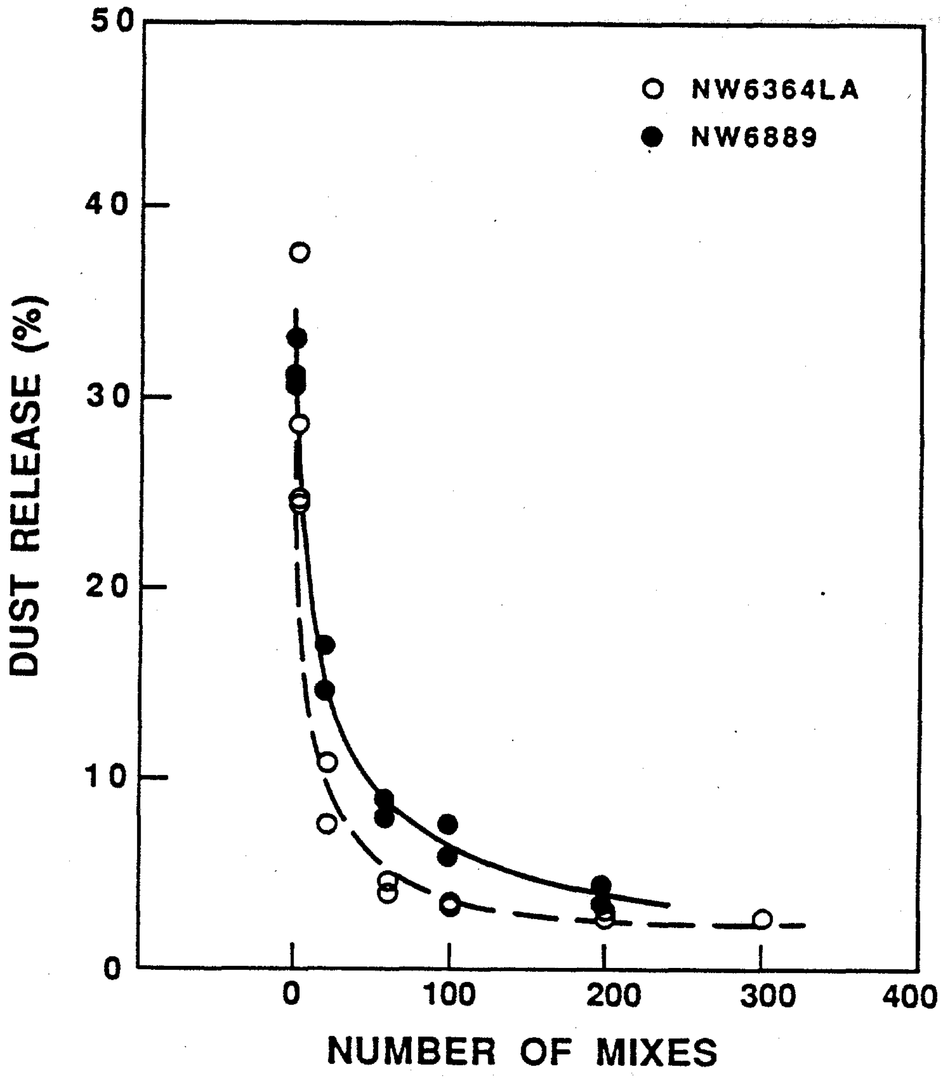


Figure 33. Effect of laboratory mixing procedure on the dust release of GTSP samples with an initial petrolatum wax distribution of 20% (application rate = 2 kg/ton).

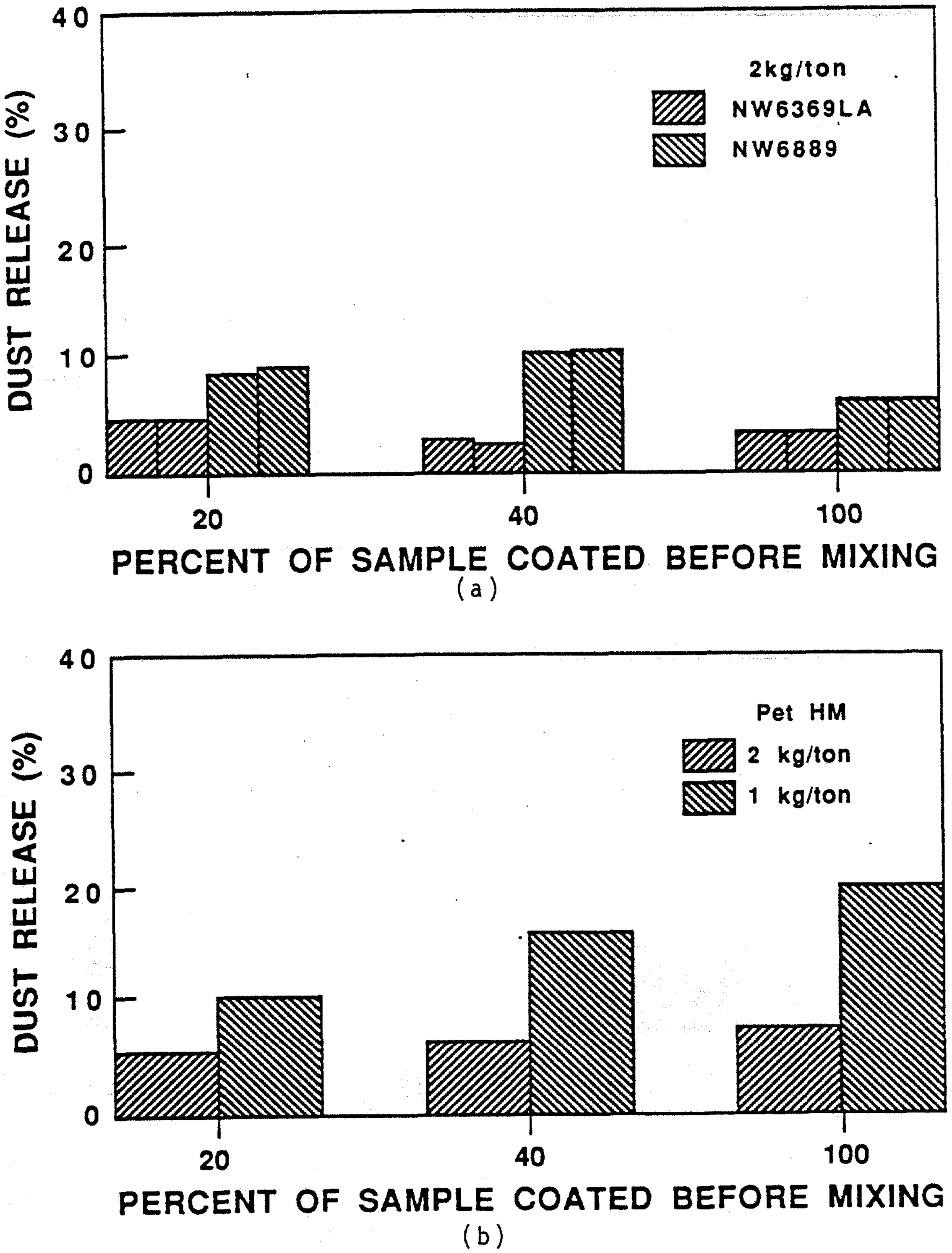
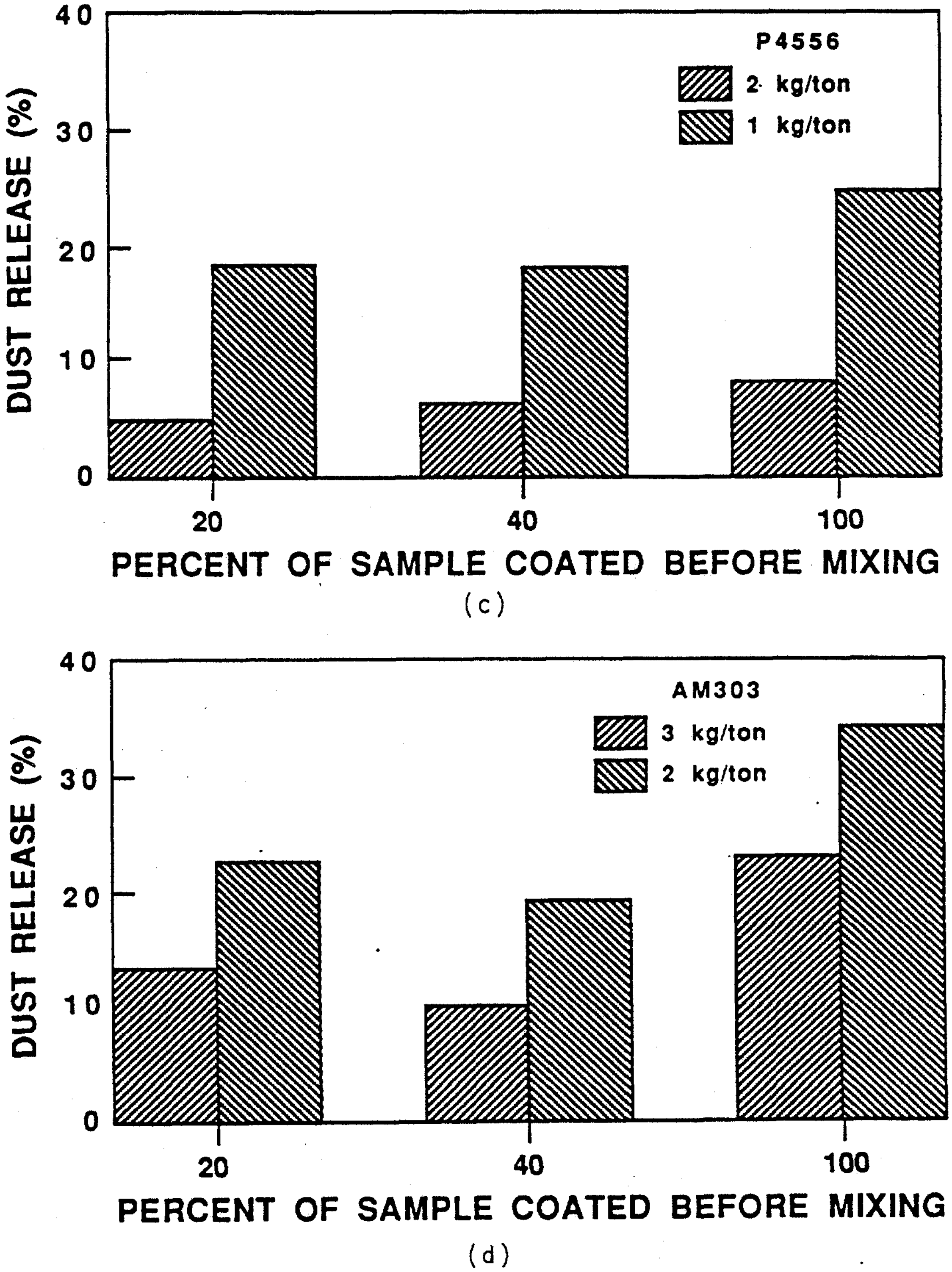


Figure 34. Effect of the initial distribution of dust suppressants on the dust release of GTSP samples. (a) NW6364LA and NW6889 (b) Pet HM (c) P4556 (d) AM303.



(c)

(d)

Figure 34. Continued.

TABLE 33

Effect of Fertilizer Temperature on the Performance of Dust Suppressants with GTSP Samples -- Series #1

Sample Number	Batch Number	Dust Suppressant	Application Rate (kg/ton)	Fertilizer Temperature			E.F.	Dust Release	Sample Treatment
				Before Spray (°C)	After Spray (°C)	After Spray & Mix (°C)	(g/kg)	(%)	
B1-3(9/9)	1	NONE	--	25	--	--	0.0488	--	Uncoated, unmixed samples.
B1-10(9/9)	1	NONE	--	25	--	--	0.0487	--	
B1-17(9/9)	1	NONE	--	25	--	--	0.0448	--	
B2-16(9/17)	2	NONE	--	25	--	--	0.0414	--	Uncoated, unmixed samples.
B2-10(9/17)	2	NONE	--	25	--	--	0.0501	--	
B2-4(9/17)	2	NONE	--	25	--	--	0.0451	--	
B3-18(9/27)	3	NONE	--	25	--	--	0.0495	--	Uncoated, unmixed samples.
B3-10(9/27)	3	NONE	--	25	--	--	0.0503	--	
B4-1(10/7)	4	NONE	--	25	--	--	0.0571	--	Uncoated, unmixed samples.
B4-2(10/7)	4	NONE	--	25	--	--	0.0546	--	
B4-3(10/7)	4	NONE	--	25	--	--	0.0512	--	
B3-11(9/29)	3	NONE	--	25	--	--	0.0334	66.9	Uncoated samples, mixed 100 times.
B3-19(9/29)	3	NONE	--	25	--	--	0.0339	67.9	
B2-5(9/27)	2	NONE	--	25	--	--	0.0383	84.1	
B2-1(9/27)	2	NONE	--	25	--	--	0.0289	63.5	
B1-2(9/16)	1	NONE	--	25	--	--	0.0359	75.7	Uncoated samples, mixed by 4 B-B transfers.
B2-14(9/22)	2	NONE	--	25	--	--	0.0372	81.7	
B2-13(9/22)	2	NONE	--	25	--	--	0.0348	76.4	
B1-5(9/14)	1	NW6364LA	2.0	25	25	25	0.0047	9.9	Unheated samples, coated and then mixed 100 times.
B1-7(9/14)	1	NW6364LA	2.2	25	25	25	0.0077	16.2	
B2-15(9/21)	2	NW6364LA	2.0	25	25	25	0.0027	5.9	
B2-19(9/21)	2	NW6364LA	2.0	25	25	25	0.0032	7.0	
B3-16(9/27)	3	NW6364LA	2.0	25	25	25	0.0026	5.2	Unheated samples, coated with 7T and mixed 20 times.
B3-23(9/29)	3	NW6364LA	2.0	25	25	25	0.0032	6.4	
B3-21(9/28)	3	NW6364LA	2.0	25	25	25	0.0031	6.2	
B3-24(9/27)	3	NW6364LA	4.0	25	25	25	0.0026	5.2	
B1-16(9/16)	1	NW6364LA	2.0	25	25	25	0.0151	40.9	Unheated samples, coated, then mixed by 4 B-B transfers.
B2-8(9/22)	2	NW6364LA	2.0	25	25	25	0.0079	22.3	
B2-6(9/22)	2	NW6364LA	2.2	25	25	25	0.0114	32.1	

NOTE: "4 B-B" means 4 bucket to bucket, "7T" means 7 turnovers.

TABLE 33 -- Continued.

Sample Number	Batch Number	Dust Suppressant	Application Rate (kg/ton)	Fertilizer Temperature Before Spray (C)	After Spray (C)	After Spray & Mix (C)	E.F. (g/kg)	Dust Release (%)	Sample Treatment
B1-14(9/14)	1	NONE	--	49.9	--	--	0.0459	--	--
B1-9(9/10)	1	NW6364LA	2.0	49.2	47.0	39.9	0.0044	9.3	Heated samples, coated, then mixed 100 times.
B1-13(9/10)	1	NW6364LA	2.0	46.8	45.8	39.2	0.0030	6.3	
B1-4(9/14)	1	NONE	--	57.9	--	--	0.0495	--	--
B1-19(9/15)	1	NW6364LA	2.2	58.6	52.8	42.8	0.0040	8.4	Heated samples, coated, then mixed 100 times.
B2-2(9/17)	2	NW6364LA	2.2	58.5	55.2	49.2	0.0053	11.6	
B3-17(9/29)	3	NW6364LA	2.0	58.1	57.8	52.3	0.0094	18.8	
B1-8(9/10)	1	NW6364LA	2.0	57.6	54.9	47.3	0.0072	15.2	
B1-11(9/15)	1	NONE	--	65.1	--	--	0.0586	--	--
B1-12(9/15)	1	NW6364LA	2.2	69.8	61.2	50.6	0.0087	18.3	Heated samples, coated, then mixed 100 times.
B2-12(9/22)	2	NW6364LA	2.0	69.1	63.4	53.1	0.0031	6.8	
B2-17(9/18)	2	NW6364LA	2.0	67.5	62.3	52.6	0.0075	16.5	
B1-18(9/15)	1	NW6364LA	2.0	64.4	60.3	49.9	0.0097	20.4	
B3-12(9/30)	3	NW6364LA	2.2	65.3	61.8	53.6	0.0155	31.1	Heated samples, coated, mixed 100 times, then reheated for 0.5 hour.
B3-13(9/30)	3	NW6364LA	2.0	64.8	60.6	51.5	0.0155	31.1	
B4-4(10/8)	4	NW6364LA	2.0	66.3	61.2	48.2	0.0149	27.4	Heated samples, coated, mixed 100 times, then reheated for 1.5 hours.
B3-14(9/30)	3	NW6364LA	2.0	64.0	63.1	52.3	0.0204	40.9	
B4-7(10/8)	4	NW6364LA	2.2	67.1	60.9	48.6	0.0158	29.1	Heated samples, coated, mixed 100 times, then reheated for 3.5 hours.
B3-20(9/17)	3	NW6364LA	2.0	66.4	--	51.5	0.0143	28.7	Heated samples, coated with 7T, then mixed 20 times.
B3-3(9/17)	2	NW6364LA	2.0	66.3	55.7	51.4	0.0087	19.1	
B3-15(9/29)	3	NW6364LA	2.2	65.3	57.0	49.0	0.0119	23.8	
B3-22(9/29)	3	NW6364LA	2.0	64.9	57.3	50.6	0.0087	17.4	
B1-6(9/16)	1	NW6364LA	2.0	69.9	64.3	50.9	0.0182	49.3	Heated samples, coated, then mixed by 4 B-B transfers.
B2-7(9/22)	2	NW6364LA	2.0	69.3	65.1	51.8	0.0073	20.6	
B1-1(9/16)	1	NW6364LA	2.0	68.7	63.6	50.5	0.0138	37.3	
B2-20(9/21)	2	NW6364LA	2.0	82.1	--	60.3	0.0063	13.8	Heated samples, coated, then mixed 100 times.
B2-18(9/21)	2	NW6364LA	2.0	79.4	72.3	58.8	0.0059	13.0	
B2-11(9/21)	2	NW6364LA	2.4	76.7	70.3	56.7	0.0045	9.9	

time. Now, when uncoated fertilizer was subjected to the same mixing process the dust release was only about 71 % i.e., 29 % of the dust was lost. Since the coating spreads quite rapidly the same dust loss will not occur with coated product. When the samples were reheated to the required temperature for about half an hour after application of the coating agent the dust release increased to the 30% level. Tests were also conducted where samples were reheated for one hour and three hours at about 65°C and the measured dust release was again of the order of 30%. Therefore, temperature and aging play a role in the loss of performance with AGTSP, with the lower melting petrolatum wax, NW6364LA, and apparently, the drop in performance occurred with a heating time of less than an hour.

A different method of mixing where the coated product was transferred from one bucket to another four times (4 B-B), similar to material transfer from conveyors, was tried. This process caused a loss of 22 % of the dust when the product was uncoated and since this mixing method was not as effective, it was factored into the calculations for the coated product. The dust release for ambient temperature fertilizer (Table 33) was about 32% and at 68°C it was about 36 %. This indicates the effect of poor mixing rather than that of temperature. Further tests were conducted where the initial distribution of the wax was improved by turning the product over 7 times (7T) during the process of coating and then mixing 20 times. The measured dust release averaged about 22% whereas with cold fertilizer the result was about 6 %.

The rationale behind the above tests was to simulate the full scale field test conditions by applying the coating agent on hot fertilizer. The results do indicate a significant increase in dust release with fertilizer temperature but because of some uncertainty about the length of time the coating was maintained at the required temperature the test procedure was modified again and a second series of tests (Series #2) were conducted using NW6364LA, a low-melting petrolatum wax, and NW6889, a high-melting petrolatum wax. During the second series of tests, five kilogram test samples were first coated in the standard manner and then mixed 100 times. The coated samples were then transferred into enameled pans and placed in an oven set at an appropriate temperature for the required length of time. Results in Table 34 show that for AGTSP, samples when no heating was done the coated samples had very low dust release values, in the 2 % range, at both application rates. When placed in a muffle furnace set at about 82°C for 30 minutes and then in an convection oven set at about 71°C for 30 minutes the final product temperature was about 65°C and the dust release was in the 30 % to 35% range for both petrolatum waxes for both application rates. In the above situations heating was quite rapid. Further tests were conducted where the coated samples were placed for 5 hours in a convection oven (Precision Model #17) set at temperature not more than 8°C higher than the required fertilizer temperature. An evaluation of the effect of fertilizer temperatures in the 49°C to 65°C range showed that at an application rate of 2 kg/ton, for NW6364LA the dust release was about 30 % at temperatures

TABLE 34

Effect of Fertilizer Temperature on the Performance of Dust Suppressants -- Series #2

Sample Number	Sample Type	Dust Suppressant	Application Rate (kg/ton)	Temperature		Uncoated E.F. (g/kg)	Coated E.F. (g/kg)	Dust Release (%)	Sample Treatment
				in pan (°C)	in bag (°C)				
B7-5(11/3)	AGTSP	NW6889	3.2	25	25	0.0462	0.0005	1.1	Coating applied on cold samples, mixed 100 times and tested without heating.
B7-9(11/3)	AGTSP	NW6889	3.2	25	25	0.0462	0.0006	1.4	
B7-18(11/3)	AGTSP	NW6889	2.0	25	25	0.0462	0.0011	2.4	
B6-10(10/27)	AGTSP	NW6889	2.0	25	25	0.0434	0.0009	2.0	
B7-15(11/4)	AGTSP	NW6364LA	3.2	25	25	0.0462	0.0005	1.2	
B6-16(10/25)	AGTSP	NW6364LA	3.2	25	25	0.0434	0.0009	2.0	
B7-11(11/4)	AGTSP	NW6364LA	2.0	25	25	0.0462	0.0011	2.4	
B6-24(10/27)	AGTSP	NW6364LA	2.0	25	25	0.0434	0.0008	1.9	
B8-1(11/15)	AGTSP	AM303	3.0	25	25	0.0448	0.0057	12.6	
B1-9(11/20)	GAMAP	NW6889	3.2	25	25	0.0434	0.0010	2.2	
B1-4(11/21)	GAMAP	NW6364LA	3.2	25	25	0.0434	0.0006	1.3	
B1-1(12/18)	IGTSP	NW6889	3.2	25	25	0.0390	0.0004	1.0	
B1-6(12/19)	GAGTSP	NW6889	3.2	25	25	0.0201	0.0007	3.6	
B5-11(10/21)	AGTSP	NW6889	2.0	70.3	62.1	0.0456	0.0128	38.1	Coating applied on cold samples, mixed 100 times and tested after heating in oven and muffle furnace for 1 hour.
B5-15(10/24)	AGTSP	NW6889	2.0	65.1	64.7	0.0456	0.0133	29.2	
B5-7(10/22)	AGTSP	NW6889	2.0	64.9	66.4	0.0456	0.0195	42.8	
B5-2(10/23)	AGTSP	NW6889	3.2	64.7	65.1	0.0456	0.0161	35.4	
B5-16(10/20)	AGTSP	NW6889	3.2	64.6	62.5	0.0456	0.0128	28.2	
B5-21(10/19)	AGTSP	NW6364LA	2.2	65.3	63.8	0.0456	0.0158	34.6	
B5-19(10/19)	AGTSP	NW6364LA	2.0	65.1	62.5	0.0456	0.0150	32.9	
B7-6(11/8)	AGTSP	NW6889	3.2	60.1	57.1	0.0462	0.0127	27.4	Coating applied on cold samples, mixed 100 times and tested after heating in oven for 24 hours.
B8-10(11/13)	AGTSP	NW6889	3.2	57.5	55.8	0.0448	0.0053	11.7	
B8-6(11/17)	AGTSP	NW6889	3.2	56.9	54.9	0.0448	0.0051	11.3	
B6-1(11/14)	AGTSP	NW6889	3.2	51.5	50.4	0.0434	0.0036	8.3	
B8-15(11/15)	AGTSP	NW6889	3.2	51.2	50.3	0.0448	0.0026	5.7	
B8-16(11/20)	AGTSP	AM303	3.0	59.9	58.3	0.0448	0.0100	22.2	
B8-7(11/7)	AGTSP	AM303	3.0	52.3	50.2	0.0448	0.0081	18.1	

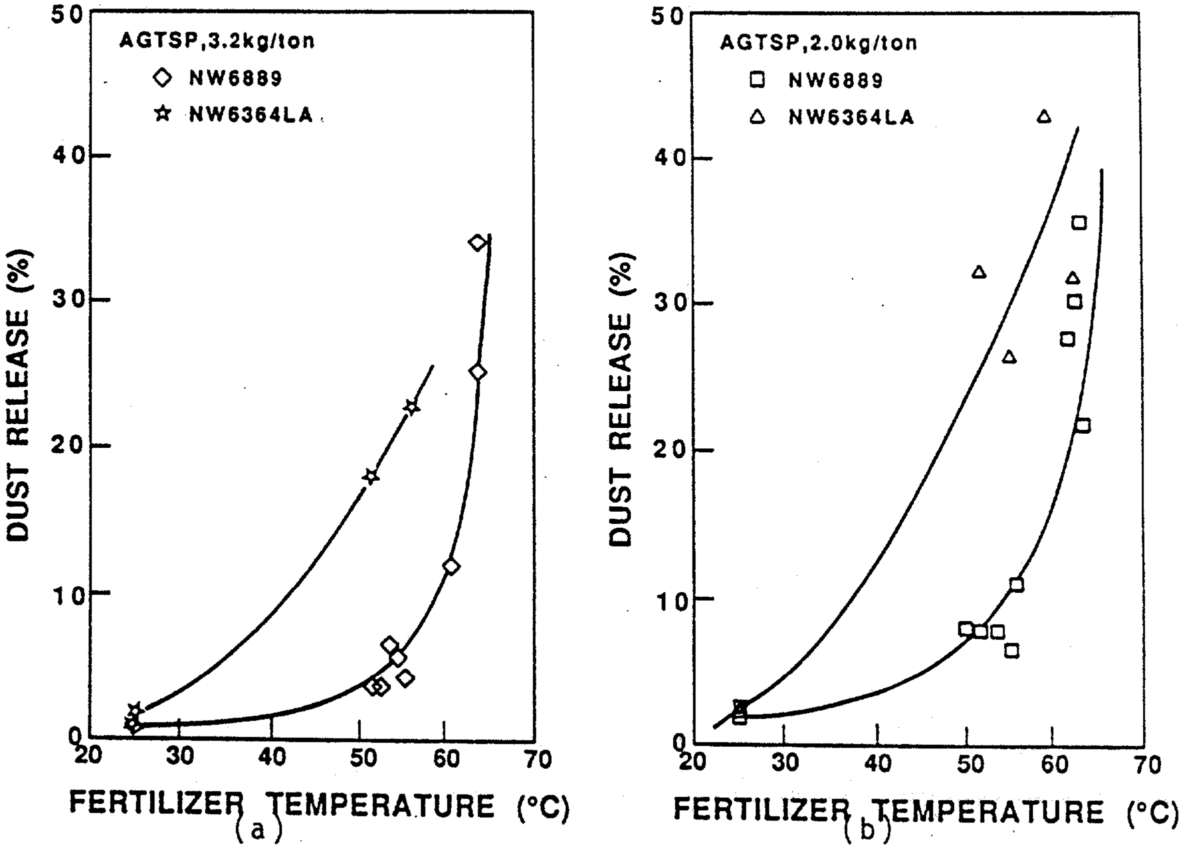
TABLE 34 -- Continued.

Sample Number	Sample Type	Dust Suppressant	Application Rate (kg/ton)	Temperature		Uncoated E.F. (g/kg)	Coated E.F. (g/kg)	Dust Release (%)	Sample Treatment
				in pan (°C)	in bag (°C)				
B6-15(11/3)	AGTSP	NW6889	3.2	63.7	62.1	0.0434	0.0150	34.5	Coating applied on cold samples, mixed 100 times and tested after heating in oven for 5 hours.
B6-7(10/27)	AGTSP	NW6889	3.2	63.7	61.1	0.0434	0.0111	25.6	
B6-19(10/27)	AGTSP	NW6889	2.0	63.4	61.7	0.0434	0.0095	21.8	
B5-10(10/24)	AGTSP	NW6889	2.0	63.1	58.7	0.0456	0.0163	35.8	
B7-13(11/3)	AGTSP	NW6889	2.0	62.6	61.2	0.0462	0.0139	30.2	
B6-2(10/27)	AGTSP	NW6889	2.0	61.7	55.8	0.0434	0.0120	27.6	
B6-11(10/27)	AGTSP	NW6889	3.2	60.7	56.9	0.0434	0.0054	12.3	
B6-17(10/26)	AGTSP	NW6889	2.0	55.8	52.3	0.0434	0.0048	11.0	
B7-7(11/4)	AGTSP	NW6889	3.2	55.6	53.4	0.0462	0.0021	4.5	
B7-2(11/5)	AGTSP	NW6889	2.0	55.4	52.7	0.0462	0.0030	6.5	
B6-22(10/25)	AGTSP	NW6889	3.2	54.8	50.6	0.0434	0.0025	5.9	
B6-3(10/26)	AGTSP	NW6889	2.0	53.9	51.2	0.0434	0.0035	7.9	
B7-20(11/5)	AGTSP	NW6889	3.2	53.8	50.9	0.0462	0.0032	6.8	
B6-21(10/26)	AGTSP	NW6889	3.2	53.0	50.9	0.0434	0.0017	4.0	
B6-18(10/25)	AGTSP	NW6889	2.0	52.2	49.9	0.0434	0.0034	7.8	
B6-14(10/25)	AGTSP	NW6889	3.2	51.9	49.3	0.0434	0.0018	4.0	
B7-1(11/8)	AGTSP	NW6889	2.2	50.2	48.5	0.0462	0.0037	8.0	
B6-8(10/26)	AGTSP	NW6364LA	2.0	62.3	57.1	0.0434	0.0139	32.0	
B5-1(10/24)	AGTSP	NW6364LA	2.0	59.2	54.7	0.0456	0.0197	43.2	
B6-9(10/25)	AGTSP	NW6364LA	3.2	55.8	52.8	0.0434	0.0100	23.1	
B6-23(10/25)	AGTSP	NW6364LA	2.0	55.3	52.8	0.0434	0.0116	26.7	
B6-13(10/26)	AGTSP	NW6364LA	2.0	51.9	50.7	0.0434	0.0140	32.3	
B6-5(10/25)	AGTSP	NW6364LA	3.2	51.3	50.4	0.0434	0.0081	18.6	
B1-7(11/21)	GAMAP	NW6889	3.2	66.7	65.4	0.0434	0.0011	2.5	
B1-10(11/20)	GAMAP	NW6889	3.2	52.1	52.8	0.0434	0.0009	2.0	
B1-6(11/21)	GAMAP	NW6364LA	3.2	61.4	60.2	0.0434	0.0005	1.2	
B1-5(11/21)	GAMAP	NW6364LA	3.2	46.1	--	0.0434	0.0006	1.3	
B1-3(12/18)	IGTSP	NW6889	3.2	62.6	60.9	0.0390	0.0079	20.3	
B1-5(12/18)	IGTSP	NW6889	3.2	55.8	54.5	0.0390	0.0019	5.0	
B1-5(12/19)	GAGTSP	NW6889	3.2	60.7	57.7	0.0201	0.0037	18.5	
B1-3(12/20)	GAGTSP	NW6889	3.2	56.9	55.6	0.0201	0.0032	16.1	
B1-10(12/25)	FDAP	NW6889	3.2	63.7	62.9	0.0541	0.0090	17.7	
B1-1(12/19)	FDAP	NW6889	3.2	59.4	55.9	0.0541	0.0044	8.1	
B1-10(12/15)	FDAP	NW6889	3.2	54.3	53.8	0.0541	0.0036	6.6	

NOTE: NW6364LA, NW6889 - Petrolatum waxes, AM303 - Oil blend as low as 52°C while with NW6889 the corresponding dust release was about 8 % (Figure 35(b)). At an application rate of 3.2 kg/ton, the dust release decreased to about 19 % with NW6364LA at the same temperature while with NW6889 the dust release was reduced further to about 4 % (Figure 35(a)). In general, the higher melting petrolatum wax, NW6889, performed better than the lower melting petrolatum wax, NW6364LA, at higher fertilizer temperatures. At fertilizer temperatures of about 60°C dust releases of 10 % to 15% were attainable with NW6889. When the heating time was changed from 5 hours to 24 hours NW6889 did exhibit some decrease in performance (Figure 36) at the higher temperatures thus indicating a clear time-temperature relationship. In comparison, AM303, an oil blend, did not respond as well under similar conditions.

Similar tests with 5-hour heating times were conducted using GTSP samples from two other manufacturers (IGTSP and GAGTSP), monoammonium phosphate samples (GAMAP) and diammonium phosphate samples (FDAP). Results show that for NW6889, the IGTSP, GAGTSP and FDAP samples all had time-temperature responses similar to that observed with AGTSP (Figure 37 (a)). However, GAMAP showed significantly different behavior with dust releases in the 1 % to 2 % range at fertilizer temperatures of up to 65°C just as was observed with fertilizers at ambient temperature i.e., not heated after application of coating agent. Similar response was observed with NW6364LA (Figure 37(b)). Tests also showed that 4-kg samples of FDAP, GAMAP and GAGTSP all responded to heating and cooling in almost identical fashion (Figure 38) thus suggesting that this factor did not contribute significantly to the differences in the results. It is therefore obvious that both NW6889 and NW6364LA are capable of being extremely effective dust suppressants, even with elevated fertilizer temperatures, in specific situations. The above results with heated fertilizer are of the same order of magnitude as that obtained with NW6364LA in full scale field tests and suggest that the time-temperature effect was a factor in the field tests. For GTSP samples, the same coating agent performed very well at low fertilizer temperatures but not at higher temperatures, all other parameters being the same.

Tests were conducted to determine if the petrolatum wax coatings could be lost by vaporization due to exposure to elevated substrate temperatures. Two sets of 5 strips of aluminum foil, spray coated with NW6889 and NW6364LA were preweighed and placed in a convection oven (Fisher Isotemp Oven Model #106G) set at 65°C for 5 hours and then reweighed. No significant weight loss was detected (Table 35) suggesting that the wax must still be on the fertilizer and could not have vaporized during heating. Since the performance does decrease with GTSP the coating is clearly not at a location where it would do the most good viz., on the granule surface. Therefore the coating must be penetrating into the granule interior leaving less on the surface and consequently decreasing the ability of the film to suppress dust.



(a)

(b)

Figure 35. Effect of fertilizer temperature on dust release at 2 application rates.
(a) 3.2 kg/ton
(b) 2.0 kg/ton

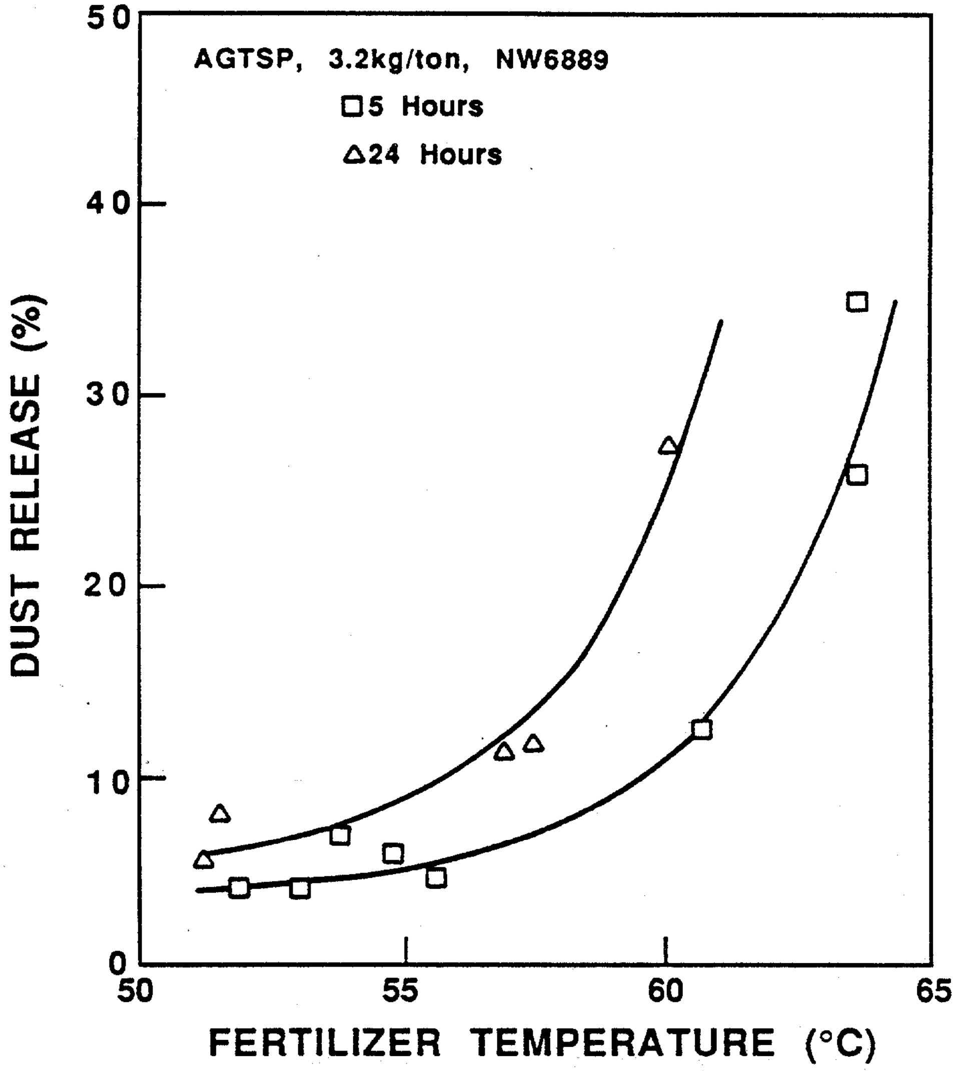


Figure 36. Effect of the fertilizer temperature on the dust release of GTSP samples coated with NW6889 after five hour and twenty-four hour heating times.

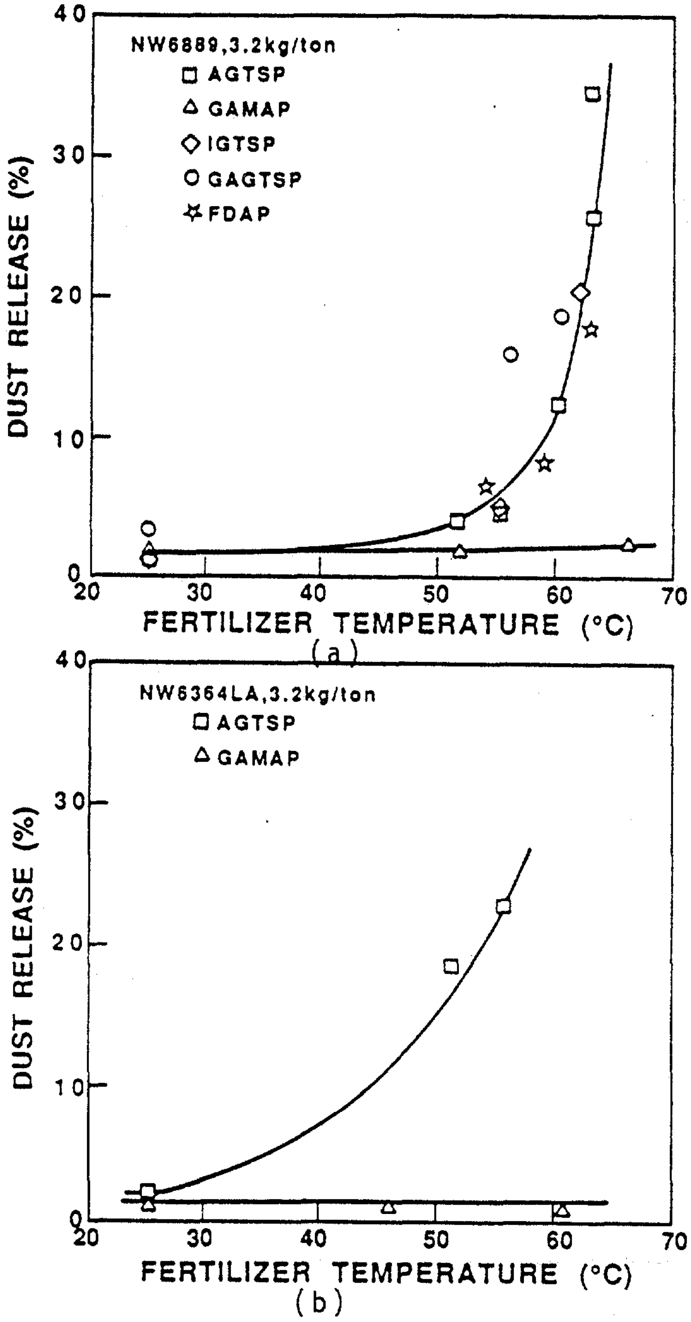


Figure 37. Effect of fertilizer temperature on dust release for various fertilizers after five hours of heating (a) NW6889 (b) NW6364LA.

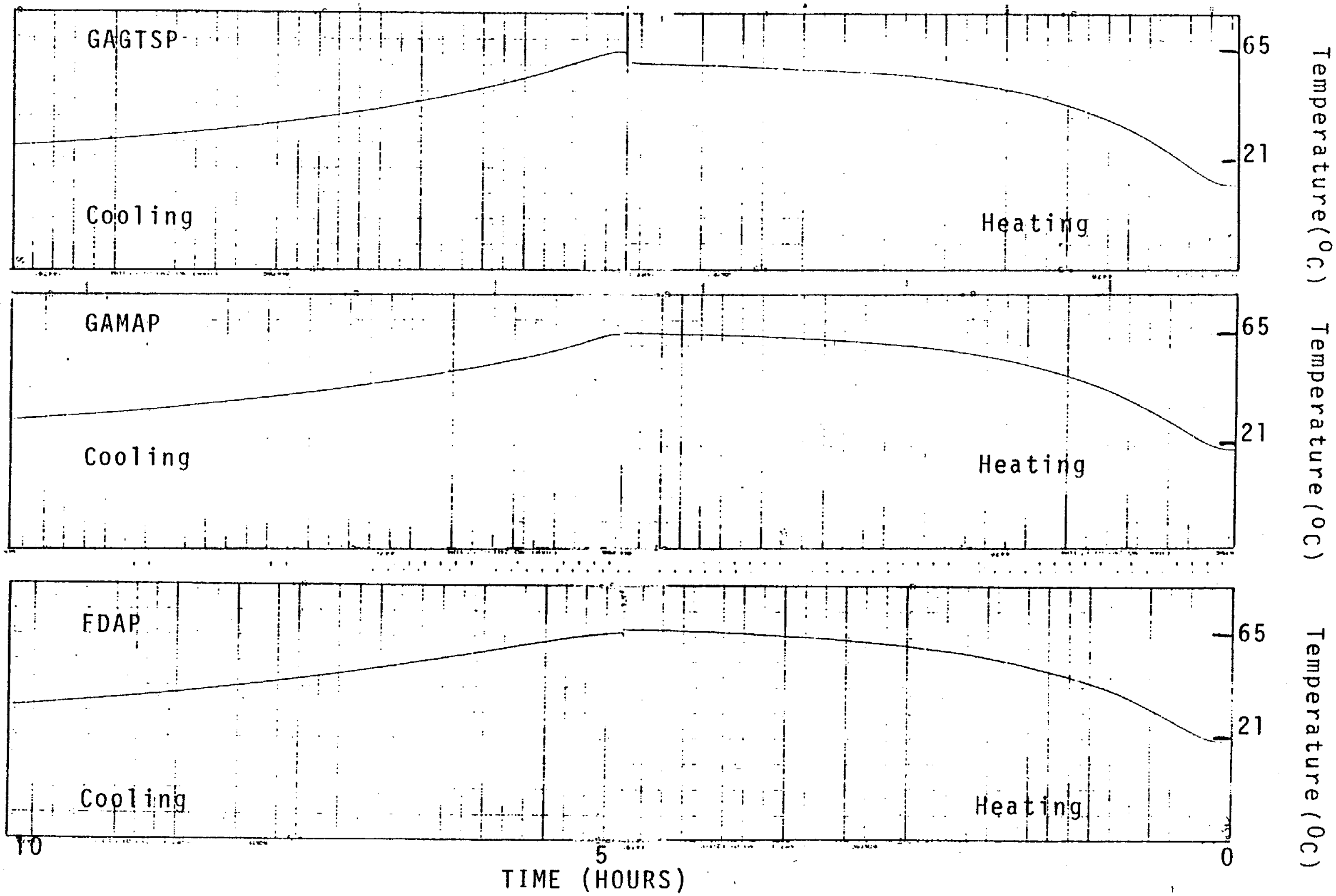


Figure 38. Response to Heating and Cooling for granulartriple superphosphate (GAGTSP), monoammonium phosphate (GAMAP) and diammonium phosphate (FDAP) samples.

TABLE 35

Effect of Temperature on Thin Films of Petrolatum Waxes

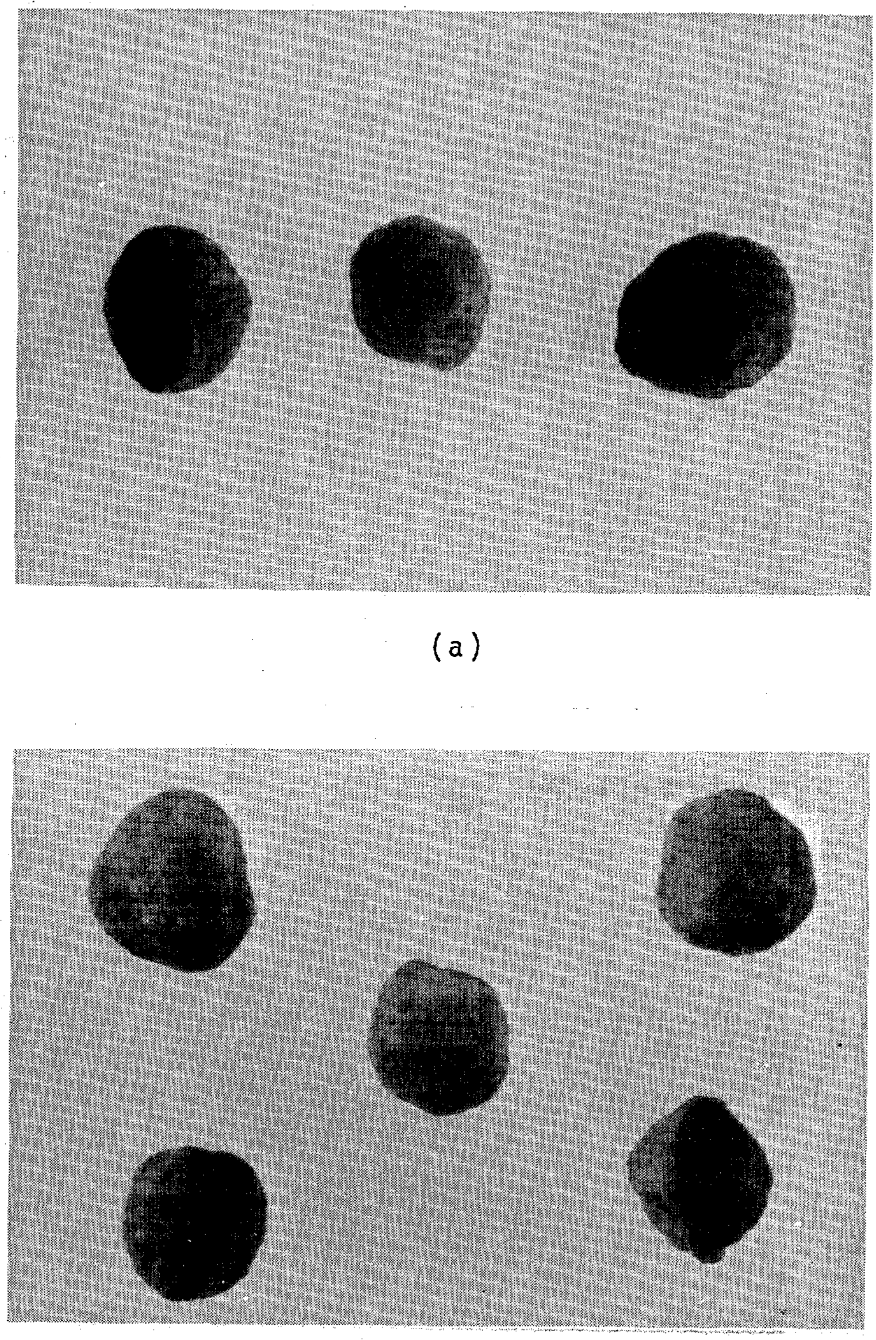
Sample I.D.	Wt. of Coating Before Heating (mg)		Wt. of Coating After Heating (mg)		Weight Loss (%)	
	NW6889	NW6364LA	NW6889	NW6364LA	NW6889	NW6364LA
1	34.86	27.68	34.82	27.85	0.11	--
2	23.22	39.68	23.30	39.59	--	0.23
3	23.84	23.60	24.01	23.55	--	0.21
4	32.16	30.92	32.21	30.90	--	0.06
5	25.62	28.64	25.62	28.75	0.00	--

NOTE: Heated in 65°C convection oven for 5 hours.

Throughout the full scale field tests and the laboratory tests just discussed, it was observed that the coated AGTSP samples appeared a lot lighter in color after heating when compared with unheated samples. This suggested that absorption within the granule interior was occurring. Now, the melting temperatures for NW6889 and NW6364LA were about 74°C and 52°C, respectively and both petrolatum waxes exhibited decreased performance at or below these temperatures. Therefore, the melting temperatures are clearly not the primary factors. The corresponding congealing points were 68°C and 29°C (minimum), respectively with the softening points being a few degrees lower. Therefore, the petrolatum waxes could become soft enough to flow i.e., be absorbed through capillary effects, at temperatures much lower than the melting temperature and these temperatures were attained both in the full scale field tests and the subsequent laboratory evaluation. To further evaluate this, uncoated granules of AGTSP were placed on a piece of aluminum foil spray coated with the petrolatum waxes. These samples were then placed in a convection oven set at the appropriate temperature near the softening point of each petrolatum wax. Significant wax pickup was observed. Photographs of granules show evidence of significant petrolatum wax pickup after about 30 minutes at 65°C. When these granules were placed in an oven set at 65°C for about 5 hours significant loss of color contrast was observed (Figure 39) again suggesting that absorption was the cause. This same technique could not be used with MAP because of the dark color of, the uncoated MAP granules. Since both the petrolatum waxes were naturally fluorescent an effort was made to detect granule penetration by looking at granule cross-sections under a fluorescent microscope but because of the small quantities of wax used (0.2% to 0.3 % by weight) the fluorescence could not be detected.

The cross-sectional view of AGTSP and GAMAP (Figure 40) shows the differences in structure. Experiments have shown that at identically elevated temperatures there is a distinct difference in performance for AGTSP and GAMAP. Therefore there must be a structural difference between the two fertilizers viz., porosity. Differences in porosity could account for the loss in performance with AGTSP and the unchanged performance with GAMAP. Results of tests using the BET technique (Quantachrome Autosorb 6) shown in Table 36 clearly indicate the significant difference in pore volume and average pore diameter for GAMAP and the 3 GTSP samples with the GTSP samples having larger pore volumes and pore diameters. For 5-kg samples of IGTSP, GAGTSP, AG SP and GAMAP the total pore volume would be 20 cm^3, 49.5 cm^3, 20.5 cm^3 and 1.15 cm^3, respectively. The volume of 16 grams of coating (application rate of 3.2 kg/ton) is about 20 cm^3. Therefore, a significant portion of the coating could be absorbed into the GTSP granules while very little would be lost within the MAP granule. Granule porosity could, therefore, be the major factor in performance degradation of coatings with GTSP samples.

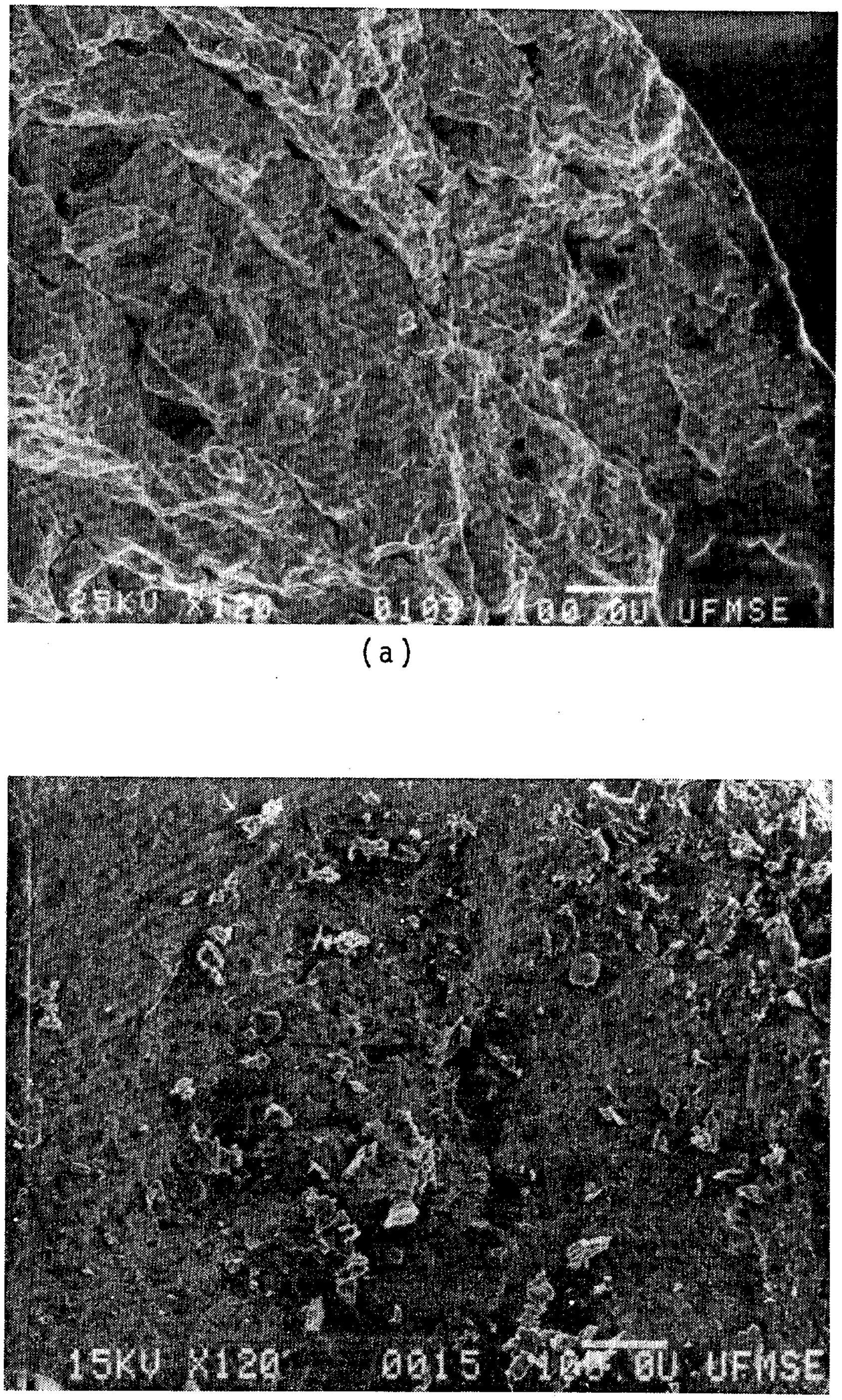
A lead tag was applied to NW6889 by dissolving about 3 grams of lead oxide in 15 ml of oleic acid heated to about 80°C and then mixed thoroughly with 85 ml of melted NW6889. The process of dissolving



(a)

(b)

Figure 39. Photographs of GTSP granules showing evidence of petrolatum wax absorption. (a) NW6889 (b) NW6364LA (left-heated; center-unheated; right-unheated).



(b)

Figure 40. Photographs of fertilizer granule cross-sections (a) GTSP (b) MAP.

TABLE 36

Porosity of Fertilizer Granules

Sample Type	Average Pore Diameter (A)	Pore Volume (cm /g)
AGTSP	434	0.00406
GAGTSP	559	0.00990
IGTSP	554	0.00399
GAMAP	71	0.00023

NOTE: AGTSP, GAGTSP and IGTSP are GTSP samples from three manufacturers.

lead oxide in oleic acid forms lead oleate, a metallic soap. This is a waxy solid at ambient temperature and is soluble in waxes. Granules of AGTSP and GAMAP were dipped in the melt and then placed in a convection oven set at 65°C for 5 hours. After cooling, these granules were cleaved with a sharp blade and then mounted on a graphite mount and carbon coated for analysis with a scanning electron microscope (JEOL Model 35C) equipped with an X-ray detector. Because of the small quantities of petrolatum wax and the even smaller quantities of lead, only a small energy range in the region of lead was scanned so that the wave form could be enhanced. The granule interior and surface near the fracture edge was studied and areas scanned were about 20 um x 30 um and not more than 100 um from the fracture edge. With GAMAP lead was detected on the granule surface, but none was detected in the granule interior for the dipped and heated samples. With AGTSP samples treated the same way no lead was detected either on the granule surface or the interior. Because of the small quantity of lead present, wax penetration would distribute the wax throughout the pores thus diluting the lead concentration even further, making it harder to detect. Samples prepared by using the regular spray coating technique also exhibited this response, with lead being detected on the unheated AGTSP surface but not on the heated AGTSP surface (Figure 41) and with GAMAP lead was detected on the surface of both heated and unheated samples (Figure 42). This observation confirmed the penetration phenomenon.

Therefore, an improper match of fertilizer and coating agent resulted in lower levels of dust suppression than expected. For GTSP and DAP, lower fertilizer temperatures would result in better dust suppression effectiveness with the petrolatum waxes used in the full scale field tests. Both the petrolatum waxes would work with GAMAP.

GENERAL CRITERIA FOR THE SELECTION OF DUST SUPPRESSANTS

A large variety of coating agents have been used to serve many different purposes. The coating agents used have included waste petroleum oils, surfactants, resins, inorganic acids, polymers, clays, diatomaceous earth and many others. The primary goals in using coating agents on fertilizers have been to reduce caking tendencies, reduce dust emissions, improve granule strength and provide timed release characteristics.

In order to be an effective dust suppressant any coating should have certain qualities which will ensure success. But, it is possible that no coating agent would possess all the required positive qualities. A knowledge of good coating qualities would however, enhance the chances of successfully finding an appropriate coating.

The most important requirement of any dust control agent is that it provide a significant reduction in dust emissions. In this work a 90% reduction level has been chosen as a minimum requirement. In addition, the dust suppressant should retain its effectiveness with age. The dust control agent must not adversely affect the handling

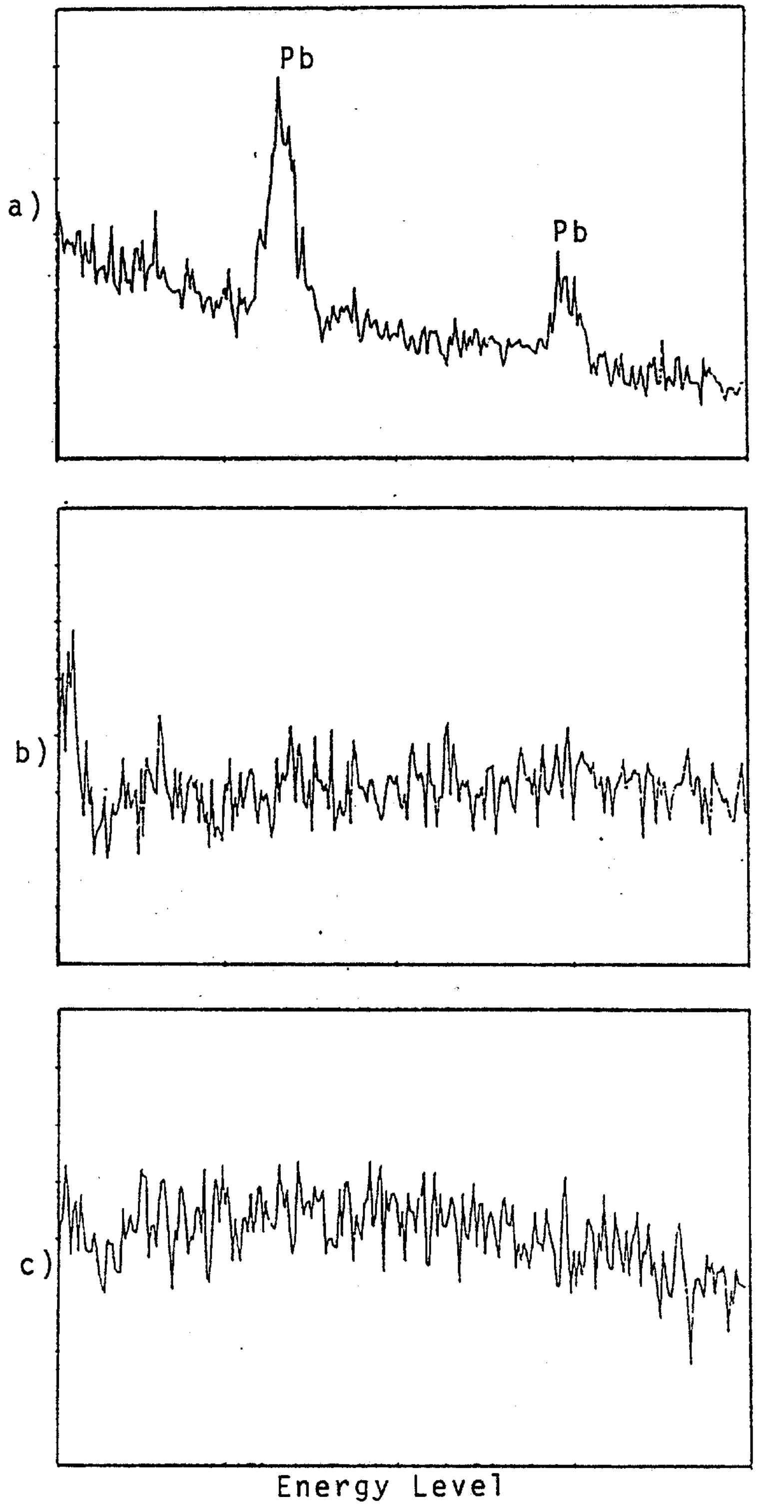


Figure 41. Elemental spectral analysis of GTSP granules coated with NW6889 tagged with lead (a) Interior of heated granule (b) surface of heated granule (c) surface of unheated granule.

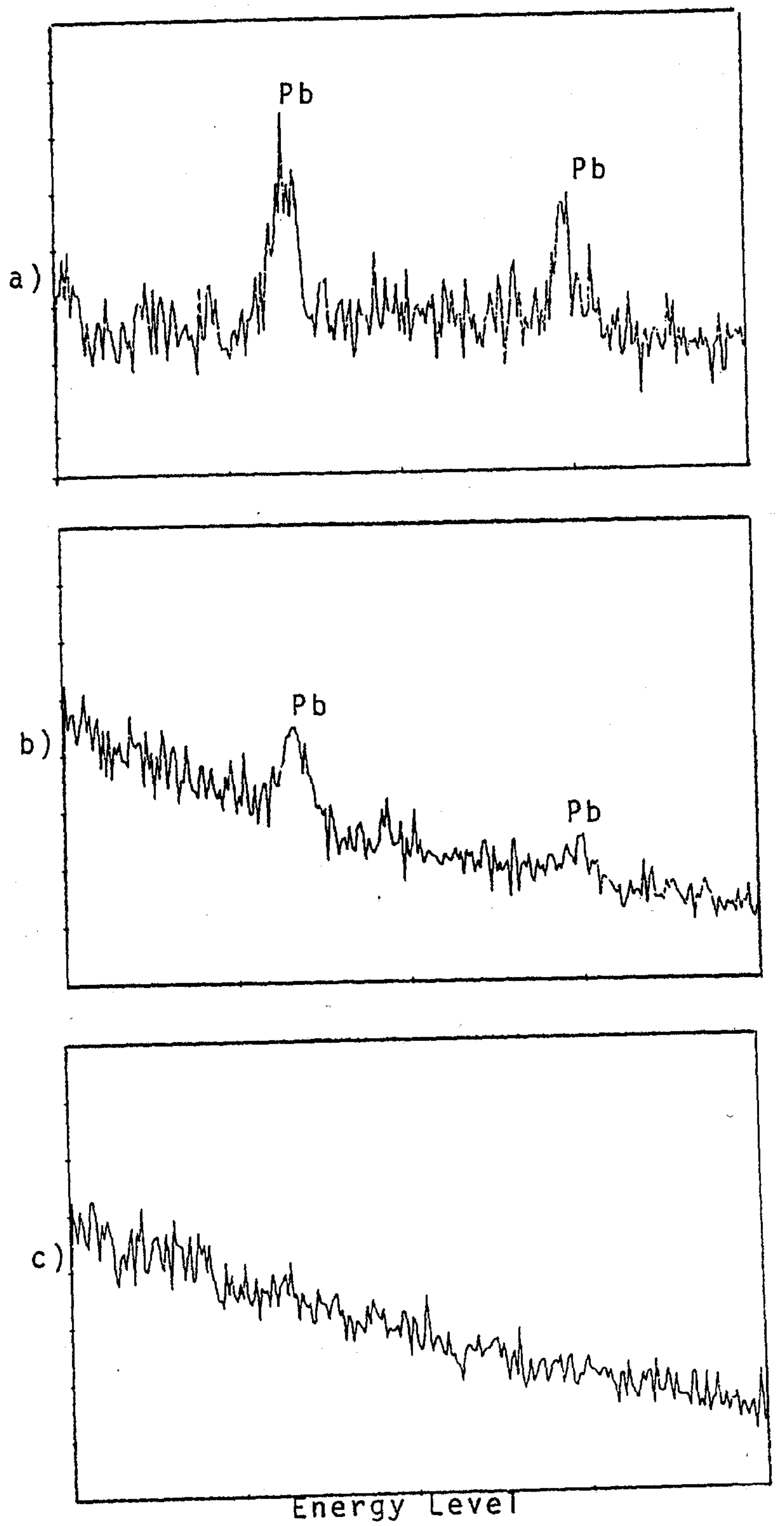


Figure 42. Elemental spectral analysis of MAP granules coated with NW6889 tagged with lead (a) Interior of heated granule (b) surface of heated granule (c) surface of unheated granule.

characteristics of the granulated fertilizer, must not be toxic or flammable and must provide the greatest benefit for the least cost. Finally, since the dust release process is a surface phenomenon whereby dust is released by breakage of surface crystal growth or by release of fine dust adhered to the granule surface, the coating must remain where it will do most good viz., on the granule surface.

During the course of this project waxes, oils and other miscellaneous coating agents were evaluated. Of these only some of the waxes were found to satisfy all the requirements discussed above. Oils and other liquid coating agents were found to have variable dust control effectiveness values. Some worked well on DAP but not on GTSP while others did not work well at all. This was due to the porosity of the fertilizer granules and the consequent capillary forces acting on surface coatings thus drawing the coating into the granule interior in the manner of a sponge.

Waxes may be classified in accordance with their origin as mineral, vegetable, animal, insect, synthetic, compounded and so on. The waxes evaluated have included montan wax, paraffin wax, microcrystalline wax and petrolatum waxes, all of which are of mineral origin. Candellila wax and carnauba wax were also evaluated and these are of vegetable origin.

Waxes, like other natural products, vary within certain limits because of their place of origin, climatic conditions, methods of collection, handling, storage and shipping, age, exposure, impurities and many other factors. In addition, these waxes are usually made up of a number of distinct chemical fractions which result in the wax not having sharply defined properties (Bennett, 1975).

All coating agents used, including the waxes, were applied by using pneumatic spray nozzles. Waxes can be applied to the substrate in two forms. First, they can be dissolved in a volatile solvent which plays no part in the final coating and only serves as a means of transferring the non-volatile solute to the substrate. Secondly, they can also be heated to a temperature beyond their melting temperature so that the melt can then be sprayed. For this particular application the first approach would not be economically feasible and would result in very high volatile organic emissions. Therefore, the second approach was the one of choice.

Since the wax is sprayed, there are some practical aspects which must be addressed. Because no liquifying agents or solvents are used, particular attention must be paid to the coating agents' viscosity and melting temperature. Both these factors strongly influence the flow and spray behavior of the waxes. Waxes with high melting temperatures require correspondingly high heating rates to keep them in a fluid state, require grater care in handling and are generally more difficult to spray. Viscosity affects the degree of penetration of the wax into the substrate. It also governs the ease with which the melt can be sprayed and thus strongly influences the choice of wax.

Viscosity in the molten state generally decreases with increasing temperatures, but excessive temperatures can lead to physical and chemical changes in the waxes which can be detrimental to their utility.

On the other hand, the blocking characteristics of a coating agent must also be considered. Blocking refers to the fusion of the coatings present on separate substrate granules and can lead to agglomeration of granules which, in turn, causes the bulk product to lose its free-flowing condition. Storage conditions, principally temperature, pressure and time, influence the blocking tendencies and as any of these three factors increases so does the tendency to block. Blocking tendencies are also significantly affected by three principal wax properties viz., melting point, oil content and ductility. In general, coatings with high oil contents have low melting temperatures and form more ductile films which do not shrink appreciably and deform without fracture. However, high oil content and low melting temperatures increase blocking tendencies and tend to accelerate aging effects on dust suppression effectiveness. Extreme film ductility is also not desirable because the film formed would be either too brittle or too deformable.

The temperature of the substrate material can affect the dust suppression effectiveness of the waxes. The higher the substrate temperature the greater the penetration of the wax into the substrate. Excessive penetration takes a significant fraction of the wax away from the substrate surface, where it is most required. Other factors which must be considered, where appropriate, are the odor, flash point, volatility and toxicity of the coating agent. Coating agents with low flash points should be avoided because of the potential fire hazard while a high volatility can adversely affect the dust emission versus age profile. Finally, cost and availability are probably the most important considerations in making a final decision about a suitable dust control agent.

It is evident that the waxes are complex in nature and that their properties are not sharply defined. Results of extensive testing show that no strong correlation exists between physical properties and dust suppression effectiveness. As a result, it is not possible to arrive at specific guidelines for the selection of waxes for specific fugitive dust suppression effectiveness values. But, based on the earlier discussion of effectiveness and handling requirements, some general guidelines in the form of a range of values of selected physical properties will, most likely, be applicable. The appropriate range of values of the selected parameters are as follows:

1. Melting temperature - 65°C to 95°C
2. Viscosity at 100°C - 70 SUS to 120 SUS
3. Oil Content - 5 % to 20%

Keeping in mind the earlier discussion, it is important to select a coating agent which is neither too ductile nor too brittle and subject to shrinkage. Petrolatum waxes based on these general criteria have been successfully used during the course of this project and are not expected to significantly affect the solubility and release characteristics of coated fertilizers (Slack, 1968). These criteria can be used to narrow the choices so that extensive evaluations may be avoided.

5. SUMMARY AND CONCLUSIONS

A vertical flow dust chamber (VFDC) was thoroughly characterized and a standard operating procedure was established. Calibration of the VFDC with monodisperse, solid aerosols has shown that the upper particle penetration limit was about 100 um and the 50 % cut size was 40 um. This was similar to the collection characteristics of the standard method for ambient air sampling of total suspended particulate matter (TSP).

Extensive use of the VFDC established that the technique was capable of providing extremely reproducible results. From tests with fertilizer samples it was determined that a deviation of less than 5% from average emission factor values could be easily attained. This fact was used to screen fertilizers from many sources and to monitor the variation in product dustiness with time for product from a single source.

The fertilizer samples used during the course of this project have had a mean granule size between 2.0 mm and 2.5 mm and the size distribution was quite narrow. The granule hardness was found to increase with increasing granule size and, in general, MAP granules were harder than GTSP and DAP granules.

Tests were conducted to show that granule fracture was not a significant mode of dust release for granular fertilizers. However, with sulfur the dust release was shown to be accompanied by significant fracture and generation of fines. The latter mode of dust release has been observed with coal, char particles and detergent powders in other studies. The generation of dust was due to abrasion of surface dust, dislodgement of adhered dust due to impact forces and breakage of surface crystal growths.

The performance of oils was found to improve with increasing kinematic viscosity and aniline point but long term performance was still inadequate with GTSP. Petrolatum waxes were found to be excellent dust suppressants regardless of substrate material and were found to be capable of continued long term effectiveness. Based on laboratory tests an intermediate scale field test (ISFT) setup was designed and used to evaluate the performance of petrolatum waxes on a larger scale. Results were very similar to those obtained in the laboratory scale tests.

Full scale field tests (FSFT) were conducted at a GTSP shipping facility handling material at a nominal process rate of 250 tons/hour. Tests conducted with two petrolatum waxes did not produce the same kind of effectiveness as had been produced during small scale tests.

It was determined that this was caused by an unanticipated set of circumstances viz., high fertilizer temperatures, slow heat loss during transport and low petrolatum wax melting temperatures.

Further evaluations in the laboratory showed that the petrolatum waxes spread quite easily by the process of mixing and the initial distribution of the petrolatum wax was not a significant factor as long as sufficient mixing was provided afterwards. The results obtained in the FSFT were duplicated in the laboratory and it was found that better performance could be obtained by using a petrolatum wax with a higher melting temperature. In addition, it was found that both high-melting and low-melting waxes performed extremely well when applied on MAP samples at temperatures upto 65°C. It was apparent that a number of factors were involved in determining effectiveness including fertilizer temperature, fertilizer cooling rate, coating aging time, petrolatum wax softening point and, most importantly, fertilizer porosity. A number of techniques were used to show that the loss in performance was due to absorption of the coating agent into the interior of granules. It was also shown that the coated fertilizers which showed poor performance had enough pore volume to absorb the coating agent.

Based on the above results it was concluded that the selection of coating agent must take into consideration process variables like fertilizer temperature and granulation technique. Other factors include melting temperature, viscosity and oil content of the petrolatum wax. From evaluations of other natural waxes it was also concluded that shrinkage and ductility of the waxes must also be considered in the final selection of a number of possible candidates.

The petrolatum waxes were found to be capable of extremely high dust suppression effectiveness at a cost comparable with the oils currently used with the added advantage of being more aesthetically pleasing, very clean and easy to spray and odorless. The performance observed in field use could have been significantly improved by selecting a more suitable petrolatum wax, one with a higher melting temperature, or by applying the petrolatum at a point in the process where the fertilizer temperature was better controlled at a lower level. If these conditions are met the petrolatum waxes are capable of reducing dust emissions from handling by about 90 % and retaining this performance in the long term.

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APPENDIX

This Appendix contains a partial list of patents relating to coating agents used with fertilizers for the purpose of reducing caking and dustiness.

1. Adams, B.E., W.H. Lawhon, and B.C. Philips, "Fertilizer Granules," U.S. Patent 3630713, December 28, 1971.
   (Coating Agent -- Vegetable Oils/High Wax Oil, Cement and Salt)

2. Arend, K.H., V. Schmide, K.C. Traenckner, K.F. Weitendorf and G. Langhans , "Fertilizer with Dust-free, Nonagglomerating, and Good Storage Properties," German Patent 2018623, November 11, 1971.
   (Coating Agent -- Polymer and Amine)

3. Cook, L.H. and S. Atkin, "Coating Fertilizer Granules," U.S. Patent 3477842, November 11, 1969.
   (Coating Agent -- Urea and Formaldehyde Reaction Product)

4. Giesicke, H.J., "Dustless Granulated Mineral Fertilizer," German Patent 2003862, August 12, 1971.
   (Coating Agent. -- Water Soluble Resin)

5. Goodale, C.D. and J.A. Frump, "Process for Improving Storability and Controlling Release of Fertilizers by Coating with Inorganic Salts," U.S. Patent 3419379, December 31, 1968.
   (Coating Agent -- Concentrated Acids)

6. Jack, J., J. Drake, D.C. Thompson and F.J. Harris, "Noncaking Fertilizer Compositions," German Patent 1767304, September 16, 1971.
   (Coating Agent -- Mineral Oil and Silane)

7. Jones, J.C. and G.C. Price,"Coating Fertilizer Granules with Silicones and Fuel Oil," British Patent 1161609, August 13, 1969.
   (Coating Agent -- Fuel Oil and Silicones)

8. Lueth, G. and R Zink , "Polyolefin Coating to Prevent Dusting or Caking of Fertilizers," German Patent 1905834, September 3, 1970.
   (Coating Agent -- Polyethylene Wax and Surfactant)

9. Robins, P.J. and P. Hayler "Compositions for Coating Granular Fertilizers," German Patent 2120385, November 11, 1971.
   (Coating Agent -- Waxy Substance and Amine)

10 Sarrade-Loucheur, J., "Coatings Preventing Dust Formation on Fertilizer Granules," German Patent 2037647, February 11, 1971.
   (Coating Agent -- Gums, Gelatins and Amines)

11. Schmidt, V., K.H. Arend, K.F. Weitendorf, K.C. Traenchner and F. Langhans, "Nondusting and Nonclumping Mineral Fertilizers," German Patent 1947874, May 13, 1971.
(Coating Agent -- Polymer, Wax and Amine)

12. Kistler, J.P. and M. Guinot, "Anticaking Compositions," U.S. Patent 4185988, January 29, 1980.
(Coating Agent -- Mineral Oil and Surfactant)

13. Tsekhanskay, Y.V., "Preventing the Caking of Ammonium Nitrate," USSR Patent 618363, August 5, 1978.
(Coating Agent -- Silicones)

14. Koch, H.K. and W. Rupilius, "Fertilizer Compositions Carrying an Aminoalkanol as Anticaking Agent," U.S. Patent 4105430, August 8, 1978.
(Coating Agent -- Fatty Aminoalkanol)

15. Pas, M.D. and I. Johnston, "Coating Particulate Fertilizers," British Patent 1527597, October 4, 1978.
(Coating Agent -- Liquid Paraffin, Surfactant and Polymer)

16. Bennett, F.W. and R.S. Nunn, "Coating Fertilizers," British Patent 1470652, April 21, 1977.
(Coating Agent -- Polyolefin Wax, Surfactant and Water)

17. Knorre, H. and J. Fischer, "Anticaking Composition for Inorganic Salts," German Patent 2456433, June 10, 1976.
(Coating Agent -- Metal Oxide, Ferrocyanide and Hydrophobic Agent)

18. Kistler, J.P. and M. Guinot, "Fertilizer Conditioner," German Patent 2664522, April 14, 1977.
(Coating Agent -- Sodium Salt of Alkylaryl Sulfonic Acid and Paraffinic Mineral Oil)

19. Bennett, F.W. and RJ. Nunn, "Coating Particles," British Patent 1462181, January 19, 1977.
(Coating Agent -- Polyolefin Wax, Surfactant and Water)

20. Takashima, H. and F. Yamada, "Urea Fertilizer Coating," Japan Patent 75129362, October 13, 1975.
(Coating Agent -- Reaction Product of Organic Isocyanate and Ammonia)

21. Steinmetz, W.E., "Prevention of Caking of Potassium Bisulfate," U.S. Patent 3936392, February 3, 1976.
(Coating Agent -- Ground Phosphate Rock)

22. Seymour, J.E., "Reducing Dust Emissions from Granular Fertilizers," Canadian Patent 980596, December 30, 1975.
(Coating Agent -- Ammonium Orthophosphate/Ammonium Polyphosphate)

23. Kahane, L., "Anticaking Composition for Powdered or Granular Fertilizers," German Patent 2550122, May 13, 1976.
(Coating Agent -- Filler, Fatty Alcohol and Amine)

24. Manabe, N. and T. Komaki, "Prevention of Moisture Absorption and Conglomeration of Fertilizers," Japan Patent 7405837, February 9, 1974.
(Coating Agent -- Salts of Tetrafluoropropionic Acid)

25. Imafuku, K., "Inhibiting Solidification of Powdered Products," Japan Patent 7452187, May 21, 1974.
(Coating Agent -- Dehydrated Ettringate).

26. Woerther, C.J., "Process for Preparing Slow Release Fertilizer Compositions," U.S. Patent 3096171, July 2, 1963.
(Coating Agent -- Plant-derived Wax)

27. Zaayenga, R., "Coated Fertilizer Compositions," U.S. Patent 3192031, June 29, 1965.
(Coating Agent -- Diatomaceous Earth and Paraffin Wax)