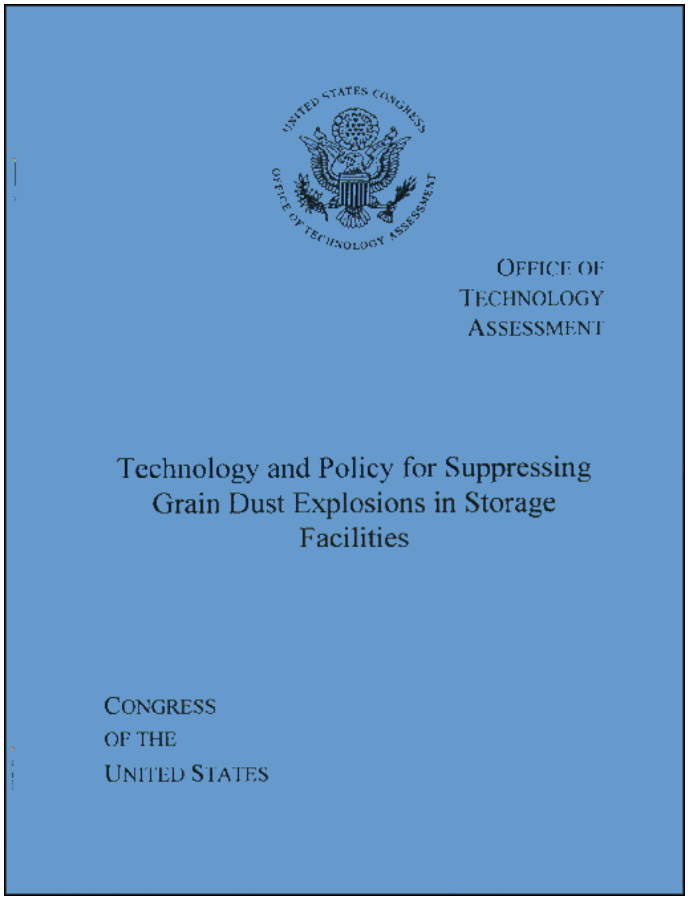
Technology and Policy for Suppressing Grain Dust Explosions in Storage Facilities

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Foreword

In 1993 the House Committee on Agriculture acted on legislation authorizing appropriations for the Federal Grain Inspection Service of the U.S. Department of Agriculture. During consideration of the bill, the Committee devoted extensive discussion to technologies used to suppress hazardous grain dust. Left uncontrolled, grain dust can become highly explosive under certain conditions, posing grave threats to the lives of facility employees and others.

To ensure workplace safety, grain handling facilities engage in a variety of activities to control the accumulation of grain dust, such as good housekeeping practices, pneumatic systems, and liquid additives. The application of liquid substances -- either water or oil -- to grain is an effective but controversial method of dust suppression. The Committee heard conflicting testimony from scientists on the effectiveness and cost of liquid additives from how effective they were for dust suppression to how detrimental these technologies were to end-use characteristics of the grain. In addition, the Committee was made aware of an ongoing federal criminal investigation about the alleged use of water systems to increase the value of grain by increasing its weight.

This report responds to the bipartisan request of the House Committee on Agriculture to assess these alternative technologies with regard to their effectiveness in suppressing grain dust, the benefits and costs of each technology, and the costs of banning the use of water as a dust suppressant. Although water can be very effective in suppressing grain dust the potential for abuse to increase the weight of grain, its moisture content, or its value is great. The most effective method of preventing the illegal application of water on grain is to remove the economic incentives from the addition of moisture. As long as the weight of grain sold can be increased, without decreasing the sale price, farmers and grain handlers will have a strong incentive to add water by any of several means. Changing marketing practices to remove the economic incentive to gain from the addition of water would be the most effective way to solve this problem.

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SUMMARY AND CONCLUSIONS

Background

The use of water as a dust suppressant was allowed by the Federal Grain Inspection Service (FGIS) in an amendment to the Weighing Provisions and Procedures of the United States Grain Standards Act "permitting the application of additives to grain for the purpose of controlling fungi, suppressing dust, and identifying grain." [Federal Register, 1987b] The final rule, published in the Federal Register March 4, 1987, provided grain handlers with a partial exemption from the ruling by the Federal Food and Drug Administration (FDA) that grain was deemed to be adulterated "if any substance has been added thereto or mixed or packed therewith so as to increase its bulk or weight, or reduce its quality or strength, or make it appear better or of greater quality than it is." [Food and Drug Administration, 1979] Research and commercial tests had demonstrated that the application of water was effective in controlling dust. However, the ruling created the potential for abuse because it relied on motive, and motive could not be clearly ascertained. The use of water for dust control raised objections from many sources and eventually led to an FGIS ruling that prohibited the use of water on grain.

The FGIS ruling which permitted elevators to use water and oil additives as a means for dust control was based on a concern over the increased number of dust explosions in grain handling facilities in the late 1970s. While the technology of liquid additives was adopted by several elevators, objections from foreign buyers encouraged several export elevators to seek alternate methods of dust control, and by October, 1993 only a few firms were still using the practice. FGIS, Office of Inspector General (OIG), and the grain industry requested hearings and a reevaluation of the FGIS ruling of 1987. The conclusions from the hearings and comments to the Federal Register were inconclusive.

Grain dust control at a grain handling facility refers to equipment and operating techniques used to reduce the generation of airborne dust during receiving, shipping, drying, and transfer operations. It may include aspiration equipment, enclosed conveyors, direct spouting, the use of liquid additives, loading spouts that entrap dust, etc. The justifications for installing dust control systems are: (1) safety --prevention of grain dust explosions, (2) housekeeping -- reducing labor required to sweep up dust settling on surfaces, and (3) regulatory -- complying with air pollution regulations.

The 1987 ruling by FGIS created controversy from the beginning. Following investigations by the OIG into possible misuse of water as a dust control measure in April 1992, FGIS was persuaded to reopen the debate on the use of water as a dust suppressant. Congressional hearings were held in 1993 to receive testimony by industry, USDA, and researchers on the need to prohibit the use of water as a dust suppressant. Following complaints from several members of the industry, including foreign buyers, about the effects of added water on grain quality, the misrepresentation of weight and moisture content, and the problems of quality deterioration, FGIS issued a preliminary ruling prohibiting the application of water to grain, requesting comments prior to final rule making. Comments received by FGIS and the congressional hearings failed to resolve the issue to the satisfaction of several members of the

agricultural committees of the House and Senate. In June of 1994, Congress requested OTA to conduct an investigation of the technology, the potential abuses, FGIS' ability to monitor water addition under licensing, the impact on grain quality and the alternative methods of implementing a prohibition of water on grain. On October 14, 1994 FGIS issued a final ruling in the Federal Register, prohibiting the application of water to grain, except for milling, malting or similar processing operations. [Federal Register, 1994]. Given the long history of the debates about adding water to grain it is appropriate that a fundamental and thorough study be made available, to resolve the issue for future generations as well as to resolve the continuing debate in legislative and regulatory bodies.

The objective of this report is to summarize the factual information on the use of water as a means of controlling dust, improving grain quality, meeting Occupational Safety and Health Administration (OSHA) concerns and Environmental Protection Agency (EPA) regulations, and reducing the danger of dust explosions in the grain marketing channel. The results of this study provide a factual basis for evaluating the beneficial as well as the detrimental consequences of the FGIS ruling.

Conclusions

The primary technologies for controlling grain dust in handling and storage facilities are pneumatic dust collection, housekeeping, enclosing of equipment, and liquid additives, with several variations on each. All of the methods are effective, to various degrees and under appropriate conditions and designs, in reducing dust concentrations at grain transfer points. None of the methods guarantee safety from dust explosions.

The application of water to grain through misting or fogging, has been demonstrated to be an effective method for dust control. Under most conditions water application is the least costly method for reducing grain dust entrainment in the air at grain transfer points. Improper, repeated or excessive water application could lead to grain spoilage and higher cost. Pneumatic dust control is an effective method of lowering the concentration of dust at grain transfer points [29 CFR: parts 1910 and 1917] although only a small fraction of the dust in the grain stream is captured and removed. The level of dust in grain will likely not be affected by this control method in that additional handling will create additional dust with breakage prone corn. Any of several methods for dust suppression, including the use of water, can reduce the probability of a dust explosion in a grain handling facility. However, there is no statistical evidence that any one method, including water, has reduced the frequency of dust explosions in the industry. Reducing the danger of explosion requires a systems-wide approach that incorporates housekeeping practices, reduction in breakage during handling, more gentle handling techniques, and an application of one or several strategies for reducing or suppressing dust at grain transfer points, loadout points, in the air, on the floor, and on the walls of the facility.

Cost calculations for the different alternatives must be based on so many assumptions about the size and type of facility and operating conditions, as well as the local, state, and federal regulations, that cost comparisons can have little relevance in evaluating the FGIS prohibition. A

wide range of costs exist for any one technology, depending on the installation and operation at a given facility. Estimating an aggregate, economic cost to the industry from a prohibition of water for dust control does not provide definitive conclusions. Very few elevators were still using water as a means of dust suppression when the prohibition rule was made effective on February 11, 1995. This suggests that the prohibition of water would impact a few firms but would have little economic impact on the total industry. In addition, prohibiting the application of water will have little impact on the ability of farmers, country elevators, and exporters to deliver grain close to the base or contract moisture. Grain handlers and producers will continue to alter the moisture content of grain through drying, blending, aeration, and other methods to meet requirements for storage, shipment, and market driven incentives.

The direct effect on quality as a result of adding 0.3 percent water to grain is very small. Grain at moisture levels on the borderline for safe storage may develop additional mold and fungi and an uneven distribution of moisture within the grain mass can potentially create storage problems; however, when applied at 0.3% or less the likelihood of significant quality problems is small. The problems communicated by foreign buyers and flour millers are based more on their perception of a problem than on scientific evidence of quality changes. Customer's perceptions are important marketing considerations. Regardless of the economic costs and benefits in the application of water for dust suppression, foreign buyers' perceptions will probably require certification that "no water has been added". Therefore, few export elevators will be willing to use water for dust suppression, regardless of the status of the regulation. Even many domestic processors (particularly flour millers) have requested a statement in the contract specifying that no water has been added.

The economic impact on the industry from prohibiting the use of water on grain will be relatively small for two reasons:

a) few firms in the market channel, other than port locations, have used water as a dust suppression technique (8.2% of the country elevators reported using water for dust control),

b) objections from foreign buyers have already required many exporters to find alternative strategies for dust control or suppression.

The strongest argument against the use of water for dust control has been the potential for abuse where grain handlers have added water to increase the weight of the grain, its moisture content or its value on the justification of controlling dust. Incentives for abuse are strong when the added water can be sold at the full price of grain. The licensing, monitoring, and supervision of the application of water would be extremely difficult at farms and country elevators. There may be cost effective strategies for controlling water application in large terminal or export elevators where FGIS personnel are frequently present.

Regulating the use of water based on motives will be extremely difficult and expensive, and inequitably applied. Given the many alternative ways in which the moisture content of grain

can be changed, uniform enforcement throughout the market channel, based on the FDA's definition of adulteration, is economically, if not technologically, impossible.

Metering devices, licensing requirements, and supervision by regulatory agencies do not address the problem created by the numerous techniques by which the moisture content of grain is changed. Absorption from humid air, blending wet and dry grain together, harvesting shortly after a rain storm or on very humid days, and normal aeration of grain in storage result in the same end product as properly applied misting or fogging. Adulteration under FDA regulations and the FGIS ruling is based on motive and procedure, not on the end result of the various practices.

The most effective method of preventing the illegal application of water on grain is to remove the incentives and the opportunity for economic gains from the addition of moisture. As long as the weight of grain sold can be increased, without decreasing the sale price per pound or ton, farmers and grain handlers will have a strong incentive to add water by any of several means. Enforcement of a prohibition against mechanical devices for water addition will not prevent the use of any of several other strategies. The use of an equivalent bushel based on the dry matter contained in the grain could effectively remove any opportunity for shippers to gain from the addition of water by any means. The equivalent bushel method has disadvantages as well as advantages, but it is the only purchasing strategy that eliminates the incentive for rewetting. Objections to the practice of adjusting grain weight on the basis of dry matter content, are more economic than technological. Conversion tables and adjustment factors are widely used by country elevators for grain with excess moisture. Applying the mathematical adjustment to grain below the base moisture has been resisted by most grain handlers and will be difficult to implement by regulation. Base moisture and adjustments in price are determined in the market place. Competition and information will be more effective than regulatory prohibitions in regulating the use of water on grain.

CHRONOLOGY OF THE USE OF WATER ON GRAIN

The issue of adding water to grain is not new. As far back as the early 1700's French grain merchants were accused of using water to "freshen" grain and swell its volume. [Kaplan, 1984]. The problem resurfaced many times between that first documented record and the current concerns over the use of water to suppress dust or to add weight to grain. The addition of moisture to overdry grain that has been stored for an extended period of time has been demonstrated to improve its appearance and odor, i.e. to "freshen".

In 1914 J.W.T. Duvel of the Bureau of Standards, USDA accused grain elevators of "spraying dry wheat with water prior to loading for shipment, for the purpose of increasing the weight" [Duvel, 1914]. In the fall of 1915, the practice of adding water to oats created a scandal of sufficient magnitude that Agriculture Secretary Houston added a statement to the regulations authorizing grades for oats: "Nothing herein shall be construed as authorizing the adulteration of oats by the addition of water, by the admixture of clippings or hulls, decomposed salvage oats, other grains, or any other foreign material, or otherwise, in violation of the Food and Drugs Act of June 30, 1906". [USDA, 1919] Again in 1925, USDA informed the grain industry that adding water to grain was "unethical and inimical to good business", and had been declared illegal adulteration under the Federal Food, Drug and Cosmetic Act [Besley, 1925] Note that the addition of water to grain **regardless of the purpose** will increase its bulk and weight. FDA officials, elaborating on the ruling, based the definition of adulteration on "the intentional addition of water to grain to increase its bulk or weight or make it appear better or of greater value..." [Hile, 1985] This interpretation required enforcement agencies to determine motive in order to differentiate between good management practices and illegal actions. FDA extended the prohibition to cover almost every alternative mechanism for adding water. Once the motive is established, the wording of the adulteration clause covers all methods of adding water including misting, aeration, uncovered trucks during a rainstorm, blending wet and dry grain together, and presumably harvesting soybeans in the early morning instead of late afternoon. Motive is exceedingly difficult to prove, especially when the end result is the same regardless of the motive.

A series of devastating grain dust explosions in the late 1970's attracted the attention of Congress. Hearings were held in 1978 before the Subcommittee on Compensation, Health and Safety pertaining to OSHA Oversight on Grain Dust Explosions. The Honorable Joseph M. Gaydos, presided. Congressman Gaydos stated the following:

> "In the last 17 years alone, 137 grain elevator explosions have been reported in 33 of the 48 contiguous continental states. Additionally, more than 29,000 grain elevator fires were reported from 1964 to 1973. This is an average loss of more than $33 million. Such statistics are shocking and every attempt must be made to improve the safety and health conditions in our grain industry." [U.S. House of Representatives, 1978].

Two of the explosions occurred at almost the same time: (1) Westwego-Dec. 1977 with 36 fatalities including seven FGIS employees and (2) Galveston-Dec. 1977 with 18 fatalities including 6 FGIS employees.

Following the 1977 grain elevator explosions, litigations, hearings, symposiums and workshops, the grain elevator industry responded by installing numerous pneumatic dust control systems. It is possible that threat of litigation was a major incentive. Law suits following a grain dust explosion seeking damages in the order of $200 million were not uncommon.

The loss of life and money associated with the explosions prompted the grain industry to initiate and fund a number of studies dealing with prevention of dust explosions. One of these studies became the basis for subsequent action by FGIS. Lai, Miller and Martin from the U.S. Grain Marketing Research Laboratory, USDA prepared a publication for the National Grain and Feed Association in which they reported on the effectiveness of water, soybean oil, and mineral oil for reducing dust emissions in corn, wheat, and soybeans. [Lai, et al., 1982a] A second publication by Lai et al. [1986] provided additional scientific data on the effectiveness of water, oil and lecithin as dust suppression additives.

Congress was also actively searching for solutions. Between 1981 and 1994, 20 bills were introduced into House and Senate committees in the U.S. Congress that related to dust control or contained a reference to the use of water on grain. The 1993 hearings revisited issues that had been raised repeatedly in previous debates or legislative proposals.

Research published by Oklahoma State University in 1981 demonstrated that rewetted and naturally wet grain had essentially the same storability characteristics. The ensuing controversy and heated exchanges in correspondence and in the press, forced the Food and Drug Administration (FDA) to clarify its prohibition against rewetting in correspondence between Dr. C. T. Haan, a professor at Oklahoma State University and the Associate Commissioner of FDA. "Paragraph 8 of your letter asks if blending of wet and dry wheat or aeration of dry wheat during humid periods are permissible practices. If the purpose of blending is to conceal damage or inferiority, make the grain appear to be of greater value, or similar reasons, such blending would be illegal. Mixing unadulterated wet wheat with dry wheat for the sole purpose of making the former suitable for safe storage is an acceptable practice. Aeration of wheat during humid periods for the purpose of increasing its bulk or weight in order to maximize profits is not acceptable and is illegal for the reasons outlined above." [Hile, 1981]

Dust control in the export market channel became an issue in Congress and the national press. Allegations were made that U.S. exported grain contained more dust than grain exported from other countries. In response to this allegation, Congress included in the Grain Quality Improvement Act (GQIA) of 1986, HR 5407 [U.S. Congress, 1986] a prohibition on the recombination of grain dust with grain once it was removed. FGIS had the responsibility of implementing this act and in this process of implementation, they requested and received numerous public comments [Federal Register, 1987]. Recombination of grain dust was separated into three classifications:

1. adding dust to grain from dust bins,
2. adding dust sweepings from the elevator floors, equipment and other areas to grain, and

3. reintroducing the dust removed from grain by a dust collection system (recirculation dust).

The final rule disallowed classes 1 and 2. In other words, dust collected in a bin and from floor sweepings could not be recombined with grain.

In 1987, FGIS issued a final rule permitting the use of additives (including water) to grain for purposes of dust control. In addition, the ruling required that if additives are applied during loading to outbound grain after sampling or weighing, or applied to inbound grain before sampling or weighing for the purpose of insect or fungi control, dust suppression or identification, the inspector and/or weight certificate must show a statement that describes the type and purpose of the additive application. These regulations, however, only applied to officially inspected or weighed grain and did not limit the application or restrict the usage of water in other situations where official grades were not used. FGIS issued the 1987 ruling after receiving comments on the proposed rule issued Nov. 26, 1984. A total of 15 comments were received during the rule making process. Only 2 commentators opposed the provision to allow additives for dust suppression. Three of the 12 supporting the rule raised questions about the possibility that it would allow the use of additives to increase the weight of grain [Federal Register, 1987b]. FGIS finalized the rule on the grounds that the provisions would allow the industry to make use of the available cost-effective technologies for reducing the danger of dust explosions.

The primary motive for the ruling by FGIS was that allowing additives would reduce the danger of dust explosions, especially at export elevators. Additional incentives for dust control and suppression were simultaneously generated by several new and revised government regulations as well as by economic and safety considerations at operating firms. Increasingly restrictive controls and limits were imposed on the industry by the Environmental Protection Agency, affecting both port and inland elevators. New regulations by the Occupational Safety and Health Administration, restricting the levels of dust allowed in designated priority housekeeping areas, provided additional impetus for finding techniques for reducing levels of dust in grain elevators.

Following the 1987 FGIS ruling, several export elevators initiated some form of water application to reduce airborne dust in their facilities and at the load out spout. However, foreign buyers, concerned about the effect of water on quality and the economic implications of the additional weight, registered complaints requesting that water not be added to their grain. FGIS received several complaints from both foreign and domestic grain merchants expressing their concern about the practice of applying water to grain regardless of the motives for the practice. [Federal Register, 1993a] and [U.S. House of Representatives, 1993] Buyers and processors correctly recognized that the end result on weight and quality depended on the quantity of water and method of application -- not on the motive. With foreign buyers requesting certification that no water had been added, exporters shifted to other strategies for dust control. Many port and inland elevators had alternative technologies in place; others installed new equipment. The alternatives were almost always more expensive, resulting in a differential cost advantage for those elevators using water misting as a dust control method versus those elevators using more costly alternatives of oil application or pneumatic systems for dust control. The economic

advantage created for those elevators using water, generated complaints from other grain marketing firms. [Federal Register, 1993a]. Some of the pressure for prohibiting water application was generated by grain handlers whose motives were related to differential economic advantage.

FGIS responded to these complaints with three additional rulings.

(1) In January 1993, FGIS amended sections 800.88 and 800.96 of the USGSA to require a disclosure on official export inspection and weight certificates whenever water was applied to export grain at export port locations. [Galliart, 1993] The action was taken in part because of the concerns expressed by foreign buyers and the potential effect that water application might have on the confidence of foreign buyers in the U.S. inspection system.[Federal Register, 1993a,].

(2) Continued complaints, industry debates, and documentation of abuses prompted FGIS to issue a proposed rule for comment that would prohibit the addition of water to grain. "FGIS has determined that water, which is sometimes applied as a dust suppressant, can be too easily misused to increase the weight of grain" [Federal Register, 1993b].

After many vigorous debates, industry associations adopted a resolution favoring the ban on water for dust control. "We are writing to you [Secretary Espy] today to urge you to take all action necessary to immediately promulgate a rule to ban the addition of water to grain, ...". The letter was signed by the Grain Elevator and Processing Society, the National Grain and Feed Association, the National Grain Trade Council, and the North American Export Grain Association. [NGFA, 1994].

Congressional committees entered into the discussion in 1993 by creating a bill in each of the Senate and the House Agricultural committees. [Senate: S.1490, U.S. Senate, 1993 and the U.S. House of Representatives, 1993]. The debate was accelerated when the House version called for complete prohibition on water addition while the Senate version would allow application for dust control under a system of licensing of the technology and supervision by FGIS. The two hearings, held specifically to discuss the issue of adding water to grain, generated more than 346 pages of testimony.

(3) On October 14, 1994 FGIS issued a final rule in the Federal Register, effective Feb. 11, 1995, prohibiting the application of water to grain, except for milling, malting or similar processing operations. [Federal Register, 1994].

The results from the hearings were inconclusive. There was strong support and equally strong opposition to the prohibition on the use of water consensus, or even a clear direction. Of 341 comments received by FGIS, 215 favored the proposal, 126 opposed it. Of those opposing the ban, 77 recommended that application could be permitted under licensing or regulation. Eleven of those opposing the ban recommended that grain be marketed on the basis of the dry matter it contained thereby removing the incentive for abuse. [Federal Register, 1994]. Most of the opposition came from grain handlers.

However, a survey of farmers conducted by Meyocks & Priebe shows that farmers supported a prohibition on the use of water on grain in about the same proportion as the several sectors responding to the FGIS request for comments. Of the 184 respondents to the phone survey, 58.2% favored the prohibition, 29.3% opposed it, and 12.5% had no opinion [Jeske, 1994].

JUSTIFICATION FOR ALLOWING APPLICATION OF WATER AND OIL FOR DUST SUPPRESSION

The large number of dust explosions and associated loss of life in the 1970's was the principle stimulus in the search for effective low cost methods for dust control. The decision by FGIS to allow the application of additives to grain for dust suppression was prompted by grain industry requests, and the ruling was issued only after research had demonstrated the effectiveness and safety of oil and water-based additives. "Industry research has shown that spraying grain with either a water- or mineral-oil based additive may significantly reduce dust emissions. The suppression of dust may be vital both in preventing elevator explosions and in reducing atmospheric pollution of the areas surrounding elevators. ... The FDA investigated the effect that additives have upon grain. FDA determined that mineral oil- and water-based additives are safe. Additionally, research conducted by and for FGIS found no conclusive evidence that mineral oil- and water-based additives are detrimental to grain quality". [Federal Register, 1984b] FGIS supplemented these research results with an investigation and supervision of an experimental oil/water dust suppression system installed at an export facility in the early 1980's. A patent for water and oil application for grain dust suppression was issued to The Andersons, March 27, 1984. [U.S. Patent Office, 1984]

Air pollution regulations, OSHA standards, insurance costs, and grain quality are other factors that must be considered in handling grain dust. Each of these four factors is discussed in the following pages.

Air pollution regulations limit the amount of dust that may be emitted that can impact the public. Prior to 1987, all particulate emissions were based upon Total Suspended Particulate (TSP). TSP was measured using a High Volume sampler that in effect samples particulates less than 45 μm [McFarland and Ortiz, 1982 and 1983]. In 1987, the criteria pollutant was changed from TSP to particulate matter less than 10 micrometers (PM10).

PM10 is measured with a special size selective inlet that removes the particles larger than PM10 so that theoretically only PM10 is sampled. Raina and Parnell [1995] reported that PM10 samples tend to under-sample PM10 and over-sample particulate matter larger than 10 μm.

In 1977, the New Source Performance Standards (NSPS) for grain handling facilities were promulgated by EPA under authority of section 111 of the Clean Air Act that limited emission concentrations from abatement devices to less than 0.01 grains per dry standard cubic foot (gr/dscf) or 23 milligrams per dry standard cubic meter (mg/dscm) (TSP). The perception of EPA and the grain industry was that the only air pollution abatement device that could achieve the 0.01 gr/dscf was a bag filter. Hence, all grain elevators with pneumatic dust control systems covered by NSPS were required to install bag filters to comply with air pollution regulations. It should be noted that the NSPS limit for Hazardous Waste Incinerators was 0.08 gr/dscf (TSP). OSHA also promulgated a new standard for grain elevator safety that included a limit of 1/8 inch fugitive dust accumulation (dust layer) near elevator legs to assist in regulating housekeeping [OSHA,1984].

Prevention of air pollution is a consequence of the enabling legislation referred to as the Federal Clean Air Act (FCAA) and its associated amendments. The FCAA empowers EPA to regulate air pollution but allows for delegation of air pollution regulatory authority to State Air Pollution Regulatory Agencies (SAPRAs). In order to be delegated the authority to regulate air pollution, a state must demonstrate an ability to perform this task effectively to include formulation of rules and regulations, permitting and enforcement. All SAPRA regulatory activities are subject to EPA oversight and scrutiny.

Air pollution regulations are typically enforced by SAPRA personnel. All SAPRA regulations must be as stringent as those established by EPA. They can limit allowable pollutant emissions to levels below that allowed by EPA but they can not allow a pollutant emissions rate in excess of these rates established by EPA.

The New Source Performance Standards for grain elevators were promulgated by EPA in August 3, 1978 [EPA, 1984]. As specified by the FCAA, the grain elevator's NSPS applies only to grain elevators with permanent grain storage capacity of 2.5 million bushels or greater and grain storage elevators, including processing plants, with permanent storage capacity of one million bushels or greater. These standards affect truck loading and unloading stations, rail car loading and unloading stations, ship loading and unloading stations, barge loading and unloading stations, grain dryers, grain handling operations, and emission control devices. Affected facilities are those facilities which commenced construction or modification after August 8, 1978. Opacity limits for particulate matter and visible emissions for grain elevators are given in Table 1.

The FCAA standards include self unloading ships, which are required to apply for an alternative emission control method, and which have for the most part selected mineral or vegetable oils. Apparently, water spray is also used in some instances. Other than for barges and ocean-going vessels, the EPA standards do not specify any particular control method. The use of water as a dust suppressant was not even anticipated by the EPA at the time the original standards were developed. All of the dust control methods discussed above can be used to comply with State and Federal air pollution emission limits. [Seitz, 1993].

OSHA regulations in the interest of worker health and safety, require standards of cleanliness. Following the widely publicized series of explosions in the 1970's, OSHA promulgated a new standard for grain elevator safety, which states that grain dust must not accumulate to levels in excess of 1/8" in priority areas. Priority housekeeping areas shall include at least the following: A) Floor areas within 35 feet of inside bucket elevators; B) Floors of enclosed areas containing grinding equipment, and C) Floors of enclosed areas containing grain dryers located inside the facility [29 CFR 1910.272]. This standard was based on a USDA task force report, which derived the ambient dust concentrations that would result if certain levels of accumulated dust concentrations were evenly dispersed into the air inside a grain elevator. [USDA, 1984]. This empirical derivation was based on a number of assumptions and the judgement of the members of the task force.

Insurance rates are influenced by the risks of fire and explosion. Dust control and suppression systems reduce the danger of fire and explosions. The National Fire Protection Association in NFPA 61B provides standards for the prevention of fires and explosions in grain elevators and facilities handling bulk raw agricultural commodities, NFPA (1994). NFPA (1994) lists requirements for explosion relief venting, antifriction bearings on shafts, dust collection systems, electrical wiring, sprinkler systems to protect the structure, and techniques to prevent or reduce dust generation. These techniques may include "reducing handling speeds, dead boxes, choke feeds, snorkel loaders, dust tight enclosures, short vertical runs, cleaning, and additives, as well as many others." Further, NFPA states that "preventative dust control is encouraged since it can effectively reduce total dust control costs as well as the demands placed on the performance of subsequent dust control techniques." The above reference to "additives" is the closest the NFPA 61B standards come to discussion of water or oil additive systems for grain.

Walker and Associates are a firm that provide inspections of grain elevator facilities and ratings which are used by some of the insurance companies which insure grain elevators. According to Walker (1994) insurance rates are adjusted to reflect risks. Risk of fire or explosion has been classified into seven risk categories based on construction to allow relief venting, fire suppression systems, sprinklers and dust collection systems, [Walker, 1994]. In addition, Walker and Associates also take into consideration whether dust control systems including oil application and formerly water application are used at grain transfer points [Walker 1994]. Lack of adequate dust control will result in a higher insurance risk. The risk categories range from "superior" to "poor" and a downgrade can increase insurance rates by about $6000 per year for an elevator of a size typically handling an average of 1 million bushels per month. The rating conditions used by one firm that provides ratings for insurance purposes provided the rating definitions shown in Appendix C. [Walker, 1994].

Grain quality has often been used as a justification for reducing the quantity of dust in grain. However, the net effect on quality is indeterminate and not easily demonstrated or proven. The removal of dust could improve the quality of grain. However, pneumatic systems remove only a small proportion of the total dust in the grain mass and once removed it is often returned before the grain is shipped. The addition of even small quantities of water to grain is usually considered detrimental to quality since it increases average moisture content. Although a few people have argued that the application of water or oil to grain improves the appearance of the grain mass, dust that sticks to the kernel worsens the appearance of the kernels and may conceal the true levels of foreign material. The use of water suppresses dust only temporarily. It is reported that following the next handling or transfer of the grain, dust emissions will return to their original level. There is an additional potential for quality losses if improper procedures or technologies are used. Even application rates less than 0.3% can create quality problems. For example, if the appropriate quantity of water is added to the grain on a moving belt, but only the top kernels of the grain mass absorb that moisture, then obviously there will be a wide diversity in the moisture content between the kernels on the top part of the belt and the kernels on the bottom part of the belt resulting in potential quality deterioration. The addition of water has also been linked to quality deterioration on the assumption that the presence of surface water on the kernels will enhance microbiological activity. [U.S. Senate, 1993].

Oil is effective for a longer period than water but still may not provide a permanent effect [Lai, et al, 1979, 1982, 1984]. In addition oil on the surface of the grain may attract small particles of foreign material which are no longer free in the grain stream to be sampled. Some buyers, especially for food use, complain that the application of any substance to the grain reduces its purity and therefore the value of the grain for use in the food processing industries.

Congressional actions and threat of legislation increased the intensity of the debate. Congress also continued to pressure the industry to reduce dust and foreign material. Prohibitions on recirculation of dust were included in several bills between 1981 and 1985, including HR-455 introduced by Neal Smith of Iowa, HR-1206 introduced by Byron Dorgan of North Dakota, and S-1121 introduced by Mark Andrews of North Dakota. These bills specifically prohibited the reintroduction of dust into the grain stream once it was removed. These controls were opposed by the FGIS industry advisory committee because of the costly and restrictive nature of the methods. However a modification of the Smith and Andrews bill was later included in the 1986 Grain Quality Improvement Act [FGIS, 1985]. The actions and threat of legislation by congress provided increased visibility and publicity that undoubtedly had an effect on strategies for dust control adopted by industry and regulatory agencies.

FREQUENCY AND CAUSES OF GRAIN DUST EXPLOSIONS

Grain dust explosions at elevators are in reality a series of explosions. The first explosion referred to as the "primary explosion" is usually small with pressures less than 2 pounds per square inch, (psi). It propagates a pressure wave and fire front. The pressure wave moves away from the location of the primary explosion at a speed of about 1000 feet per second (fps) while the fire front follows at about 10 fps. The movement of the pressure wave results in secondary concentrations that are subsequently ignited by the relatively slow moving fire front. Secondary explosions can result in rupture pressures in excess of 100 psi.

Four ingredients are required for a grain dust explosion:

- oxygen,
- ignition source,
- fuel, and
- containment.

All four ingredients must be present for an explosion to occur. An explosion can be prevented by eliminating any one of the four ingredients. An oxygen-free environment in grain elevators is obviously impractical. OSHA and the FDA have established numerous regulations and guidelines to eliminate the ignition sources. The fuel for a dust explosion is the grain dust in suspension in the air at or above the minimum explosive concentration (MEC). Most experts use 50 grams per cubic meter (g/m^3) as the MEC for grain dust. If the dust concentration at a grain transfer point is less than the MEC an explosion will not occur even if all other ingredients are present. A concentration of 50 g/m^3 is so high that a person standing in this concentration would not be able to see their fingers one foot away. The engineering strategies for reducing the probability of dust explosions include pneumatic dust control, liquid additives, enclosed conveyers, direct spouting and other equipment and techniques that reduce and/or eliminate dust emissions. These strategies are directed at reducing the concentration of grain dust suspended in air at grain transfer points and thereby eliminating one of the required ingredients for an explosion -- fuel.

The effectiveness of using dust control systems, or oil or water additive systems, in preventing grain dust explosions, is dependent upon reducing the concentration of grain dust entrained in air at grain transfer points to levels below 50 g/m^3. Properly designed pneumatic dust control systems can capture a portion of the dust entrained in air at the grain transfer point, diluting the concentration to less than the MEC. Oil additive systems consist of an application of a food grade quality oil to the grain surface that results in fine dust particles "sticking" to the surface of the grain kernel thereby not being entrained in air at the transfer point. Hence, the concentration of grain dust at the transfer point will be less than the MEC. The use of water for dust suppression consists of using a fine mist spray at the grain transfer point. Lai et al [1979, 1982] reported that water sprays at 0.3% by weight were effective in suppressing 60-75% of corn dust emissions at grain transfer points [Lai et. al., 1982]. One or more of these dust removal and dust suppression strategies have been implemented by most grain elevators.

The fourth ingredient for an explosion (containment) is essential for an explosion to occur for the obvious reason that the rapid build up of pressure results in a rupture of the containment vessel (explosion). Without containment, an explosion will not develop and ignition of a dust

cloud results in a fire only. However, containment is also required for the attainment of the very high concentrations of grain dust needed for an MEC to occur. Fifty g/m^3 is such a high concentration, it will not occur without containment. Some industry personnel have indicated that other elevator design changes can reduce MEC or reduce major damage if a primary explosion occurs. Explosion venting is a design concept used with elevator legs to vent the pressure and fire front of the primary explosion outside the elevator, thereby reducing the probability of the more devastating secondary explosions. Locating elevator legs external to the main elevator has a similar objective [U. S. House of Representatives, 1993].

Strehlow [1982] found two major sources of dust explosions: (1) the bucket elevator, considered to be the most dangerous piece of equipment in the elevator; and (2) smoldering dust. Strehlow concluded that poor housekeeping practices that allowed accumulation of dust provided the fuel for an explosion. A heat-generated fire or a spark provided the ignition source for an explosion. [Strehlow, 1982]

In summary, prevention of grain dust explosions is associated with eliminating one or more of the ingredients, other than oxygen, associated with dust explosions. Removal of ignition sources eliminates "ignition". Pneumatic dust control and dust suppression using oil or water additives reduces the concentration of grain dust suspended in air at a grain transfer point. This approach addresses the fuel for a grain dust explosion which is a concentration of grain dust at or above the MEC. Concentrations of dust below the MEC do not explode. Hence "fuel" is eliminated. Safety measures have been adopted to minimize damage given that a primary explosion occurs. These include fire and explosion suppression (Fenwall) systems. If a primary explosion were to occur in the leg, the faster moving pressure wave activates fire suppression systems to quench the slower moving fire from the primary explosion, prior to ignition of secondary explosions. Explosion venting is used to vent the products of combustion from the primary ignition prior to ignition of secondary explosions. The engineering concept associated with explosion venting is that a release of the pressure valve prior to formation of secondary MEC's will prevent secondary explosions. Housekeeping addresses the potential fuel for a secondary explosion given that a primary explosion occurs. If the layered dust associated with housekeeping were eliminated, a secondary explosion would not occur.

However, no one strategy is adequate by itself. Sound safety management should include a total system approach in which dust control is only one element. Prevention of dust explosions requires careful layout and design of plants and equipment, including: moderating speed of equipment; enclosure and negative pressurization of equipment; utilizing controlled venting; and minimizing grain breakage and dust separation by avoiding long free-fall drops, sharp angles, and steep inclines in the grain-handling process. Design and layout should be supplemented with aspiration and air-cleaning equipment at critical points in the process. Proper preventive maintenance and housekeeping practices and the installation of heat-sensing, shaft speed monitors, and motion detection equipment in the operation is also recognized as essential by the industry.

Cargill illustrated the diversity of approaches in their testimony at the congressional hearings. "We do not have pneumatic dust control in every one of our grain elevators. We do not use a mineral oil addition in every one of our grain elevators. We use a combination of housekeeping practices, maintenance practices, and design practices, and we supplement it with

aspiration where it is needed or with pneumatic dust control where it is needed and in some cases, we use mineral oil." [Botos, 1993].

The number of dust explosions in the United States is small relative to the number of grain handling structures in the market channel. However, many of these explosions are of such a severe nature that percentages and probabilities are of little consolation given the loss of life and property damage in historically documented explosions such as those in Westwego and Galveston in 1977. "Fortunately, since 1977, the number and magnitude of dust explosions has significantly declined due to a greater safety awareness and better engineering. Smoke and heat detectors, improved bearings and buckets, fire and explosion suppression systems, improved cleaning techniques, and better dust control methods have contributed to a safer work environment".[Galliart, 1993].

There is no particular geographical pattern to the explosions, nor has there been any success in predicting them. Many elevators, where conditions leave the facility highly susceptible to a spark and explosion, have never experienced problems. Other elevators with relatively good records of cleanliness have been involved in very serious conflagrations. It is therefore difficult to identify any one strategy that will guarantee elimination or reduction in the probability of an explosion occurring at any particular location.

A comparison of the number of grain dust explosions per year since 1960 supports the theory that there has been a decrease in the frequency of explosions since the highs of the 1980's (Figure 1). The unusually large number of explosions in 1980 (many of which were not associated with grain dust) distorts any trend using annual averages that include that year. With the exception of 1980, grain dust explosions and total explosions in grain handling facilities are highly correlated (Figure 1). It is difficult to identify causality in the annual pattern. It has been hypothesized that the number of explosions was highest in those years when export volume was highest. [Parnell,1981]. In the five year period from 1980 to 1984 export volume and the number of explosions reached an all time high. Five year averages show an increase in number of explosions from 1960-64 through 1980-84 and a decline for the next two periods. Export volume for all grains shows a similar pattern (Table 2).

Annual data fail to support the theory that the number of explosions is a function of export volume. The simple correlation coefficient between volume of grain exports and the number of grain elevator dust explosions from 1960 to 1994 was 0.45. The relationship shown in Figure 2 illustrates the low correlation. Not all of the explosions occurred at export elevators. There are obvious exceptions to the weak pattern that exists. The number of explosions during the high export periods of 1979-81 and 1988-89 ranged from 14 to 62 (Table 3).

The limited amount of data on the number and causes of grain dust fires and explosions, makes it unlikely that any control method would be highly correlated with a change in the number or the probability of an explosion occurring. During the eight year period following the FGIS' approval of water as a dust suppressant the average number of explosions per year was 7.25. The 5-year averages for the three decades from 1960 through 1974 were 7.0, 7.4, 8.6.The next three decades were nearly double in the number of explosions the previous three decades -- not an adequate basis for assigning causality. In addition, during this same time period there were many changes in technologies, practices, and regulations that had direct and indirect effects on the ingredients required to generate dust explosions. Although the FGIS safety manager reported that "there's been no explosion where water was used" [Milling and Baking News, 1993], this is not conclusive evidence that water application will eliminate explosions, since thousands of elevators not using water for dust control also have had no explosions in their history.

IMPROVED AIR QUALITY

Complying with OSHA standards is an incentive for elevator managers to utilize dust control systems in order to prevent grain dust explosions and provide a safe, healthy working environment for their employees. SAPRA and EPA regulations limit the allowable emission rate of particulate that can impact the public off property. The primary difference between these two regulatory agencies is that OSHA's goal is worker safety and health and EPA's goal is prevention of air pollution impacting the public downwind from the facility.

The use of water for dust suppression is an effective strategy for complying with air pollution regulations. In most installations it has the potential to be significantly less costly than pneumatic dust control. A large number of grain elevators may be required to install dust control systems in the near future as a consequence of states implementing the federal Clean Air Act (FCAA) amendments and the use of erroneous emission factors by many agencies [Parnell et al, 1994b]. This issue is controversial and it will require some time for the FCAA to affect change. The following discussion is included to illustrate the magnitude of the air pollution problem in the grain handling industry.

The Federal Clean Air Act (FCAA) amendments passed by Congress and signed by the President in November 1990 have had a major impact upon the regulation of air pollution in the United States. The unique aspect of the FCAA is that the funding mechanism of air pollution regulation is included in the law. All major sources[1] must pay an annual emission fee of $25 (or more) per ton of pollutant emitted every year. There is no upper limit on this fee. As a consequence of the FCAA, most State Air Pollution Regulatory Agencies (SAPRAs) have had to increase their staffs including additional inspectors and engineers, in order to implement the EPA mandates. Regulation and enforcement of air pollution regulations will cost the grain handling industry millions of dollars annually. Many of these regulations will be incorrectly applied [Parnell, 1994].

SAPRAs are using the incorrect emission factors to calculate the annual emission rate. These factors are on the order of 30 to 100 times higher than is actually emitted by the elevator. Parnell et al. (1994) has indicated that a more accurate uncontrolled emission factor for a country elevator should be 0.1 to 0.3 lbs. of particulate per ton of grain handled. The published EPA AP-42 emission factor for country elevators is 8.6 lbs. of particulate per ton; for feed mills it is 9.8 lbs. per ton.

"Many in the grain industry have long suspected that the numbers in AP-42 are too high. For example, the document says 8.6 lbs of dust are emitted into the atmosphere for every ton of grain handled. NGFA officials believe that's at least two to four times too high". [Grain Journal,

[1] A major source is any stationary source or group of stationary sources located on one or more contiguous or adjacent properties that directly emits or has the potential to emit 100 tons per year or more of any pollutant (including any major source of fugitive emissions of any such pollutant, as determined by rule by the Administrator). The 100 tons per year criterion can vary if the facility is located in a non-attainment area or if the pollutant is a hazardous air pollutant. Sources subject to NSPS are major sources irrespective of their emission rate [40 CFR 70.2].

1995]. According to Parnell this number is 30 to 100 times too high. The grain industry may not realize the magnitude of these errors and the economic impact of using incorrect emission standards. Additional documentation about the accuracy of emission standards can be found in Parnell *et. al.*, 1994b

U. S. Senator Charles Grassley, R-Iowa has introduced legislation that may provide some relief to grain handling operations. If this legislation passes, EPA will be required to use annual operating conditions for grain handling facilities. In effect, it will eliminate the controversy associated with the guidance from EPA to SAPRAs with regard to "potential to emit". EPA has defined potential to emit as "the maximum capacity of a stationary source to emit any air pollutant under its physical and operational design." [40 CFR 70.2]. Many state regulators have interpreted "potential to emit" to mean that even though a feed mill or grain elevator may only operate 1000 hours per year, this facility has the potential to operate 8760 hours/year. The applicable regulation [40 CFR 70.9] establishes that fees are to be calculated on "actual emissions". The controversy at the state level relates to the definition of "actual emissions". Some states use the permit allowable emissions from the facility's permit to calculate "actual emissions". Some facilities have source sampling results that indicate their actual emission rate is far less than their permit allowable. To illustrate this controversy consider an operation (not subject to NSPS) permitted to emit 50 tons/year (t/y) while operating for 1000 hours (1000 t/h). In most states, a 50 t/y emission rate would exempt the facility from having to pay the Title V emission fees because it would not be classified as a major source. However, this operation has the potential to emit 438 t/y and would be classified as a major source (> 100 t/y). All major sources pay Title V emission fees.

In addition, Senator Grassley's bill provides an exemption from the requirement to obtain a Federal Operating Permit (FOP) for facilities that emit less than 100 tons/year but are covered by the New Source Performance Standards (NFPS). Many SAPRAs have interpreted the Federal Clean Air Act and guidance from EPA as follows: Any grain elevator with a storage capacity of more than 2.5 million bushels must obtain an FOP without regard to how much dust is emitted. This means that an elevator must obtain an FOP if it meets the NSPS criteria even if its calculated emission rate was less than 100 tons/year. This bill would provide relief for these facilities. Although EPA regulations clearly state that sources covered by NSPS are included in the new permitting program mandated by the 1990 amendments to the Clean Air Act, EPA does not dictate to states how they should determine whether a facility is classified as a major source.

GRAIN QUALITY CONSIDERATIONS

Fine materials and dust are frequent sources of complaints by foreign buyers. The soft starch in the corn kernel is powdered as a result of impacts during repeated handling between U.S. farms and the processing plant of the foreign buyer. [Hill et. al., 1979]. The fine powder created, clings to the surface of the kernel, giving it a gray or whitish appearance. During movement of the grain stream this fine powder becomes airborne, creating emission problems. The lower the moisture content of the grain the more readily it breaks and the more dust that is created during subsequent handling. High temperature rapid drying also adds to the breakage susceptibility creating more breakage and therefore more dust. The use of water is effective in suppressing the dust. This temporarily solves the problem of dust emission, although EPA testified that they did not believe that the prohibition of water as a dust suppressant would necessarily increase dust emissions. [U. S. House of Representatives, 1993].

However, the use of oil and water does not remove the dust, but only serves to conceal its presence. In the case of water the effect is temporary since the water is reabsorbed by the kernel and the dust again becomes a free agent. In the case of oil the dust may be retained for a much longer time period, attached to the individual kernels.[2] However, in neither case is the quality of the grain improved in the sense of its intrinsic properties, its milling attributes, or its end-use value. The dust is still present and the problems created for milling by excessive dust and less than whole kernels remains. If pneumatic systems are used to physically remove dust and not return it to the grain stream, quality would be improved throughout the market channel and in the final processing plant, but the improvement in quality would be insignificant since only a small proportion of dust in the grain is actually removed and additional dust is created during subsequent handling. No technology removes all dust and some that is removed is re-introduced.

Many millers have specified that neither oil or water may be added to grain. Negative effects on milling and flour quality from the addition of oil have been reported from a study conducted by a commercial miller. [Reid, 1987] A representative of U.S. Wheat Associates stated that "Oil has adverse effects on flour yield and color, both important factors in determining the profitability of the milling operation. Oil can also cause bacteria and other undesirable particulate materials to adhere to the wheat kernel, particularly in the crease of the kernel, and therefore reportedly can raise bacteria counts in flour. Because some of the oil is detectable in the resulting flour, it may have adverse effects on the quality of the end product. Also many products are now made from whole grain, which include all the oil sprayed onto the wheat". [U.S. Wheat Associates, 1993]. However, conclusions from analysis conducted by Lai et al. [1986] indicated that "functional properties of grain, as measured by SRW wheat milling, baking, and cake making, were not altered as a result of oil treatments". Several millers and processors have taken a conservative approach, refusing to accept grain if oil has been applied. "A number of U.S. flour millers, both large and small, prohibit the use of oil dust suppressants on the wheat they buy. For example, one of the largest U.S. baking companies stipulates in their contract terms that no oil is to be added to the wheat from which their flour is milled. A major U.S. brewing company has a

[2] Most of the research material available for this study related to the use of food-grade oil, without differentiation to mineral or soybean oil. Differentiations between mineral and soybean oil within this report were only made when specifically supported by research results.

nearly identical contract term: no oil is to be added to the malting barley which they buy. Each of these domestic buyers of grain, and its products, has identified negative impacts of oil additives on end-use quality. U.S. Wheat Associates is concerned that the elimination of water for dust control will result in increased use of oil and a deterioration of the quality reputation of U.S. wheat exports". [Jacobson,1993].

The addition of water has an additional effect upon quality of the grain. Considerable research has been conducted to evaluate the effect of rewetting grain on its storability, mold growth, and accuracy of moisture measurement [Bloome, et. al., 1982].

Sauer et al. [1992] stated that the combination of moisture content, temperature and time determine the storage risk of stored grain. Basically, starch cereal grains with 13.5% moisture or less can be stored without damage from storage fungi. For soybeans the moisture needs to be 12.5% or less for long term safe storage. Table 4 from Sauer et al. [1992] indicates that as moisture content of starchy grain increases, the equilibrium relative humidity also increases and different species of fungi are able to metabolize and grow.

Table 4 shows that as moisture content of starchy grains, such as corn, increases, the equilibrium relative humidity also increases. Depending on the grain temperature, this will create conditions favorable for metabolism first by Aspergillus halophilicus, then A.restrictus and A.glaucus, eventually A.candidus, and A.flavus. A.flavus is one of the fungi species known to produce aflatoxin when certain growth conditions are present.

If grain moisture were to increase by 0.3% points, the relative humidity of the air in equilibrium with the grain goes up by about 2 percentage points. [ASAE,1994]. If moisture content goes up, relative humidity goes up and vice versa. The presence of this additional relative humidity or water activity, can be just enough to create conditions for more rapid fungal growth and metabolism.

Hall [1983] provided rewetted corn samples to FGIS for storage studies for 2 months and 1 year at storage temperatures of 70 to 75°F. Corn samples were in the 14.04 to 16.16% moisture range and 0.2% water was added by weight. Corn total damage was determined after 60 days of storage and found to be higher for the rewetted corn but not significantly higher for 3 of the 4 corn sample sets. For the corn stored for 1 year, the wetted corn had significantly higher total damage than the non-wetted corn. Thus, depending on the initial moisture of the grain, the length of time to be stored and the temperature of the storage conditions, an additional 0.2% water addition, will make conditions more favorable for fungal growth and may or may not result in additional fungal damage being great enough to change the total damage grading factor.

Other factors affecting fungal growth are presence of broken and fine materials, dust, and percentages of non-whole kernels. For the purpose of assessing likelihood of fungal infection, the maximum moisture content present is the controlling factor, rather than the average moisture

(which is measured with normal moisture meters). For this reason, even a small pocket of moist grain will allow fungal growth to start, which by their metabolism reaction, converts starch and oxygen into carbon dioxide with the dangerous by-products of moisture and heat. Thus, once fungal growth starts, the fungi will be able to create enough heat and moisture to make neighboring grain kernels moist enough and warm enough to promote even more fungal growth. Without massive aeration or major cooling, or turning of the grain, fungi left to metabolize will create moist conditions favorable for more and more species of fungi, which may with time consume the starch in the grain. Moderate fungal growth also creates heat and moisture that makes conditions more favorable for insect growth.

An additional concern of adding water relates to the credibility of the official certificate. "The official certificate reflects the quantity and quality of grain that has been properly stowed aboard the vessel. ... Based on existing scale tolerances, the grain loaded should be within 0.05% of the official certificate. The addition of 0.2% of water by weight could possibly increase that figure to as much as 0.25%." [Marshall, 1982].

COST AND EFFECTIVENESS OF ALTERNATIVE TECHNOLOGIES

Research and experience have demonstrated differing degrees of effectiveness of the different technologies used for dust control. There are technical as well as economic advantages and disadvantages of the alternative methods. The three primary forms of dust control (pneumatic suction, water, and oil) can be effectively used depending on elevator design and end-use grain requirements. Good housekeeping practices supplement other strategies by reducing the amount of dust at rest in the elevator. The methods are often integrated for optimum performance. The following paragraphs review the strengths and weaknesses of each of the three techniques.

Pneumatic systems

A Regulatory Impact Analysis performed by OSHA in accordance with the grain facilities rulemaking determined that compliance with the standard was economically feasible. That analysis included a recommendation for the installation of pneumatic control measures. A number of firms have installed pneumatic systems in their flagship facilities, suggesting that they are cost effective. Operating firms have reported that pneumatic technology has been effective in meeting California regulations, requiring lower levels of airborne grain dust, and that these systems are economically feasible. [Mestrich,1993].

Pneumatic suction systems, while generally effective in reducing the amount of dust in the air, possess some shortcomings. In addition to being extremely expensive to install, such complex systems are difficult to properly maintain, consume a great deal of electricity, and may be a focal point of elevator explosions. Although some dust is removed with the pneumatic system, many elevators subsequently recombine that dust with the grain to avoid any weight loss and to provide disposal of the dust. Dust that is not recombined creates it's own handling and storage hazards.

A common misconception is that pneumatic dust control systems remove all dust from grain. They do not; they remove only about 5% of the dust in the grain at a transfer point. They do lower the dust concentration. [Parnell,1993].

Pneumatic systems can be economical for even small grain elevators. A quote from the 1993 House of Representative hearings provides an illustration. "Some of them have been installed in grain elevators like the local one where I live that only had 48,000 bushels of capacity. That elevator was built 50 years ago. It has not had any problems." [Richard,1993].

The pneumatic systems are not without their technical problems. The Westwego export elevator was rebuilt following the 1977 explosion with a radical new design. Instead of using bucket elevators, a series of inclined belts were used to elevate the grain. In addition, a system was designed to eliminate all recirculation of captured dust. Every grain transfer point had an associated dust control system. The system was designed to handle the grain dust so that no dust was recirculated. However, the system did not significantly lower the level of dust in the grain. The goal was to lower the concentration of dust at the transfer point to less than the MEC so an explosion would not occur. Dust content of grain before and after dust control systems was measured and it was found that the level of dust in the grain did not change. The system was later modified to include some recombination of grain dust to provide a technically and economically

feasible system for removing and storing dust. The dust control systems were located on the river at the receiving and shipping points, 1/2 mile from the head house. Since dust was not to be recirculated it had to be collected in a bin at the river and conveyed to the head house pneumatically. This system of collecting dust and conveying it to a bin on the river and subsequently to a bin at the head house so that it could be shipped by rail was not reliable. Whenever a technical problem occurred in the dust collection and conveying, the elevator had to cease unloading and/or loading of grain.

FGIS requested a study on the recombination/recirculation (R/R) ruling and the classification of dust according to its location in the handling system, to determine its economic impact on the grain industry, on grain quality, and on safety. The results of this study were as follows: [Parnell et. al, 1992].

1. Disallowing R/R will not significantly reduce the dust content of exported grain. The amount of dust removed from the air is very small relative to the amount of dust in the grain.

2. No measurable quality improvement would be achieved if R/R were to be disallowed.

3. Disallowing R/R would increase the grain dust explosion hazard in export elevators. (This conclusion was based on three factors. Disallowing R/R would: (a) increase the number of locations in the facility that would have Minimum Explosive Concentrations (MECs) as a consequence of the required materials handling systems for captured grain dust; (b) result in an economic incentive to reduce the number and volume-rate-of-flow of dust control systems in order to reduce the volume of bin dust captured; and (c) there would be an incentive to replace pneumatic dust control systems with oil additive systems, although liquid additive systems degrade with time.

Assuming an annual export volume of 4.5 billion bushels of grain:

4. The fixed cost of disallowing R/R would be $29 million (0.6 cents per bushel).

5. The annual cost of disallowing R/R would be $38 million per year (0.8 cents per bushel).

6. If R/R were to be disallowed, approximately 200,000 tons of grain dust (3.2 pounds of grain dust per ton for 4.5 billion bushels of exported grain) would be collected annually, adding to the cost of marketing or disposal by export elevators. The 3.2 pounds per ton of grain dust captured was the estimated total amount of grain dust that would be captured by all of the pneumatic dust control systems operating at an export elevator. One of the export elevators in this study had 52 operating dust control systems.

7. Dust control systems are <u>not</u> grain cleaning systems. They are used to decrease the concentration of dust entrained in air at a grain transfer point. Dust control systems are in reality dust <u>management</u> systems.

<u>Housekeeping Practices</u>

The effectiveness of housekeeping in reducing dust explosions differs between primary and secondary explosions. Primary explosions are always the first explosion in the elevator. When someone refers to the "cause" of the explosion, this is in reference to the cause of ignition of the primary explosion. The pressure wave leaving the primary explosion entrains residual dust into secondary explosive concentrations that are ignited by the relatively slow moving fire front from the primary. Good housekeeping is probably the single most important factor in reducing the risks associated with secondary grain dust explosions. Even with effective airborne dust controls, some dust will escape and settle on floors, equipment, ledges and other surfaces. [Miller, 1983].

The National Academy of Sciences (NAS) in a 1982 report recommended that the most cost effective step to reduce explosions was improved control of grain dust within elevators through concerted housekeeping programs. NAS recommended automatic suction and manual cleaning systems be installed to remove dust from within closed elevator spaces, particularly elevator "legs", the portion of the facility through which grain is transported from ground level to the top of elevator silos. Today, these systems are in place in nearly every facility. [Botos, 1993].

Use of Liquid Additives.

Liquid additive application systems require sophisticated equipment to control application rates and to assure adequate coverage of the grain surface. Not all oil application systems in use today are sufficiently sophisticated to assure adequate coverage. This requires continuous monitoring of grade, quality, and viscosity of the oil used in the application. Water quality and application rates also must be carefully monitored. Inappropriate application or repeated applications may cause detrimental biological or microbial activity in grain [Steele, 1993].

Effectiveness of oil as a dust suppressant. Research results have demonstrated that food grade oil applied to grain reduces grain dust concentrations at grain transfer points [Lai et. al., 1979, 1982, 1984, 1986; Parnell et al, 1989). For example, Lai et al [1986] states that "Oil treatments effectively reduced dust emissions in commercial grain handling facilities. Environmental dust levels were lowered to less than 0.015 g/m^3". FGIS concurred with the conclusion that oil applications are effective. "In terms of its effectiveness, all indications from research and what we have observed are that oil is effective". [Shipman, 1993]. However there exists some disagreement over its effectiveness under various conditions. Parnell reported that the oil dust suppression mechanism can be overwhelmed by extremely dusty grain and is not as effective on milo as it is on corn. In addition, there have been reports that the effectiveness of the oil application degrades with time.

"A 1982 study on additives found that while both water and oil applications result in significant dust reductions, oil application is very slow to develop dust control as it requires extensive mixing in the grain flow. As a result, the impact of oil on dust control is negligible at the most explosive and critical location of the grain elevator transfer process -- the elevator legs. ... Some companies have stated that research shows that the addition of food grade mineral oil at the rate of 0.03% by weight to corn reduces dust accumulation on the gallery floor by 90%. There are three problems with this statement. First, 1982 ARS research found that 0.05% (not 0.03%) reduced dust concentration by 90% on the gallery floor. Second, explosions are most likely to occur in the leg of the elevator, which precedes the gallery, where oil is not as effective.

Third, an application of 0.03% or 0.05% would be illegal since the FDA limit on the application rate of food grade mineral oil is 0.02%. Again, oil is not a full or equal substitute for water-based dust suppression". [Jacobson, 1993].

Another concern with oil additives, from either mineral or vegetable based sources, is the potential residual build-up through repeated additions in the grain distribution channel. Water either evaporates or is absorbed, in which case it can be detected by moisture measurements. Oil additives remain with the grain and go unmonitored in standard grain analysis. However, the high cost of oil is a deterrent to overapplication and FGIS reported that "..we do not see overapplication because of the cost of the oil". [Shipman, 1993]. However, it is not possible to determine total application and whether the 200 ppm (1.5 gallons per 1000 bushels) FDA limit has been exceeded, because there is no method for detecting the level of oil that has been applied to grain. It is possible that oil could be applied to grain at the country, inland terminal and terminal elevators without it being detected by FGIS. The proposal to limit the application rate of water to grain to no more than 0.3% [Parnell, 1993] would, if promulgated, result in an application rate of water of more than 10 times the FDA application rate limit of oil or 22 gallons of water per 1000 bushels.

Effectiveness of water as a dust suppressant. There exists some disagreement over water's effectiveness under various conditions. For example, the water dust suppression mechanism can be overwhelmed by extremely dusty grain. The strongest argument for water-based dust control is its proven ability to immediately suppress dust at grain elevator legs, as shown in the research conducted by the USDA Grain Marketing Research Laboratory [Lai et al, 1979, 1982, 1984, 1986] The elevator legs contain the greatest concentration of suspended grain dust during routine operation. Virtually all grain dust explosions are chain-type reactions triggered by primary explosions. Approximately 23% of the known locations of primary explosions is attributed to elevator legs [USDA, 1984].

Lai et. al., [1979, 1982] reported the following conclusions from research using water sprays to control corn dust.

- At least 0.3% of water was required to achieve dust suppression. [Lai et. al., 1982].
- Water spray provided suppression of 60-75% of dust emissions.
- A water spray may help provide fire protection as well as dust explosion protection in a grain elevator.
- A system to add water is inexpensive and easy to install.
- Proper application of water spray (1.0%) will not spoil the grain if the grain contains less than 13 percent moisture." [Lai et. al., 1979].

Lai et. al., were primarily concerned with wheat where moisture content in exported grain is low. However, FGIS showed that 100%
of corn exported in 1991-92 had a moisture content of 13% or greater. [FGIS, 1993].

In 1982, the USDA Grain Marketing Research Laboratory completed a study that had been requested by the NGFA. That study found that additives applied properly and at correct locations can reduce fugitive grain dust [Lai et al., 1982a]. Water addition at the leg dramatically reduced the fine dust particles and increased the moisture content of the dust, thereby lessening the electrostatic activity within the leg, reducing ignition source volatility. Water-based dust suppression was found to decrease the danger of an explosion at this critical point.

U.S. Patent 4439211 by Don E. Anderson, Glenn E. Hall, and Kevin M. Foley of The Andersons describes a method of controlling food dusts using a water spray, a water plus emulsifying agent spray, or a water plus emulsifying agent and oil spray. Applications were made to streams of corn, wheat, and soybeans prior to a loadout point or discharge location. They reported that there is a time delay after the particles are dampened and there needs to be a time during which the particles must remain consolidated before going to the discharge location, if the spray is to effectively reduce opacity. Opacity was defined as a measure of the reduction in light that is transmitted through an environment. In one application, 14% moisture corn exited from a chute to a short free fall drop. In the free fall drop, a nozzle was placed on each side of the stream, then the grain was consolidated on the chute where it was relatively undisturbed for 3 seconds before it exited the second chute. Opacity at the end of the second chute was effectively reduced from 33% down to an acceptable level of 20% when 0.1% water (weight water/weight of grain) was applied. With 0.2% water application, opacity of 43% was reduced to 20%. With 0.05% water application, opacity of 28% was reduced to 20%. The moisture was absorbed into the corn with out spoilage.

In further work done under US Patent 4439211, the effect of grain agitation by mixing after spray application was determined. In all cases the less agitation that occurred after spraying, the more effective the spray was in reducing opacity. Dust is distributed through out the sample and spraying only affects the dust particles near the surface (approximately 5%), which are the same particles that would likely become entrained in the air at the next transfer point; however if considerable mixing occurs after spraying and before the next transfer point, the remaining dust particles (approximately 95%) are untreated and are available to contribute to high opacity and dusty conditions.

In full scale tests with work done under US Patent 4439211, grain was delivered by belt to a garner, sprayed from two sides while in free fall, using the device described in the patent and loaded on to a hold of a ship. Opacity was measured at the loadout spout going into the ship. Data from Figure 14 of US Patent 4439211 shows that 31% opacity was reduced to 6% with 0.35% water applied and to 8% with 0.21% water applied. With 0.01% water applied, the lowest level tested, opacity was 28%. They also tested emulsifying agents with water, and mixtures of oil and water with an emulsifying agent. Water-oil emulsions of 1% oil - 99% water and 10% oil - 90% water were slightly more effective than water alone in controlling dust at the lower application rates. Their results indicated that to reduce opacity at a loadout point, it is critical to have very little grain mixing after the water has been applied. The method described in Patent 4439211 was reported to be able to reduce opacity (visible dust emissions) at a loadout point located outside an elevator; it did not claim to reduce dust explosion hazards.

Peavey reported that their outside insurance underwriters agree that water-based systems, when utilized in combination with pneumatic suction systems, present a preferred approach to controlling dangerous air suspension and accumulations of grain dust. [Jacobson, 1993].

There are potential dangers associated with improper applications. Lai et. al., [1986] also reported that if too much water is added, grain will spoil and lodge in bins requiring manual extraction, a dangerous process. In addition, wet grain often adheres to and cakes enclosures around belts and buckets. This increases static electricity in these enclosed areas, which can become an ignition source for dust explosion.

Those requesting a prohibition on the use of water on grain to suppress air borne dust identify several limitations and disadvantages. Since water is quickly absorbed by the grain and grain dust, it provides only temporary reduction. As the water evaporates or is absorbed, the dust may again become entrained in the air. However, the argument that water should not be used because it is only a temporary solution, is negated by the way that dust collection systems are used. Dust collection systems too, are temporary because the collected dust is "returned and recirculated" back into the grain stream. This is a permitted method to dispose of dust because it has been effectively argued to be safer than storing dust in bins. [Dust stored in bins eventually has to be removed and disposed of and the handling of this dust may in itself result in an explosion.] Whether very elaborate dust collection systems are used or water spray mist is used, the solution only takes care of one transfer point, because the dust either is put back in the grain or, in case of water, it was never removed and suppression is temporary.

The most significant objection to the use of water for dust suppression has been the potential for abuse. The Office of the Inspector General (OIG) stated that at least a fourth of the elevators investigated by OIG had used a firehose or some crude method for applying water to grain. The abuses were found mostly at the country elevators. [Stang, 1993]. In addition OIG reported that "as a result of water application to grain, we found poor housekeeping practices on many of the facilities that were using water. Excessive buildup of caked material around belt end bearings we feel are creating extra safety hazards in these elevators". "...many elevator employees at houses that have used or have purported to use water for dust-suppressant systems have told us in testimony they did not like the use of water, they did not like the use of water specifically because of safety problems" [Stang, 1993].

Based upon the results of several studies dealing with water spray applications one could conclude that a limitation of 0.3% total application rate of water would be ineffective since 0.3% was needed for each application point and at least five locations would be candidates for dust suppression in a grain elevator. However, these studies by Lai et. al., [1982a, 1986] used water spray systems rather than "fogging" systems that are reported to produce extremely small water droplets (in the 10 micron range). Fogging systems treat the air space around the grain more than the grain itself and consequently place very small amounts of liquid on the grain.

Zalosh [1977] proposed that water spray could "inert" strategic locations such as grain transfer points, elevator legs, receiving and shipping points by reducing MEC below the critical level. His concept is the same concept used to cool hot gases with water sprays. The energy

required to change liquid water into vapor can be extracted from hot gases resulting in a more humid cooler gas. If sufficient water were present to absorb the combustion energy of the burning dust, an explosion would not occur. He estimated that 0.24 pounds of water per pound of dust would be needed to inert a grain transfer point. The latent heat of vaporization of water (the amount of heat energy required to change 1 pound of water to 1 pound of water vapor) exceeds 1000 BTUs per pound. Grain dust will typically have an energy content of 7,000 BTUs per pound. If the grain had a typical dust content of 2 lbs/ton, an application rate of 0.24 pounds of water per pound of dust would be equivalent to 0.024% (by weight).

Zalosh's 0.24 lb (water) per pound of dust may be low [Zalosh, 1977]. The process of vaporizing 0.24 pounds of water would absorb the energy of 0.034 pounds of dust (15 grams). If 5% of the dust in grain were to be entrained in air at a grain transfer point, 2 pounds of dust per ton would result in 0.1 lbs of dust per ton of grain entrained in air at a transfer point. A primary explosion would release 700 BTU that could be inverted by 0.7 lbs of water. This 0.7 pounds of water per ton of grain, which is equivalent to an application rate of 0.035% by weight, could result in preventing grain dust explosions irrespective of whether the application resulted in dust suppression. Hence, a low level application of a water spray has the potential for preventing grain dust explosions other than dust suppression. The ability to realize this potential is dependent on meeting the conditions of 3 assumptions: 1) the level of dust in the grain is no more than 0.1% by weight. 2) only 5% of the dust that is present is entrained in the air at any transfer point; and 3) all of the water applied is in liquid form, in order to have the ability to provide the 1000 BTU's per lb required to absorb energy to vaporize the water. Much of the water applied by fogging nozzles is in vapor form.

The use of water fogging to suppress dust is a new technology that appears to be effective under experimental conditions. Allison [1993] reported effective dust suppression using a water "fogging" system at application rates of 0.02% and less. "In my opinion water fogging systems can be designed to apply a limited amount of water to grain. The argument that water spray or fogging is technologically infeasible is not accurate. It is my understanding that systems have been installed [Parnell, 1985]. Matsumora et. al., [1991] tested the effectiveness of the water fogging system for reducing concentrations of less than 10 micrometers of particulate matter (PM10) downwind from an almond hulling plant. His results suggested that "PM-10 concentrations can be reduced up to 50% at an almond huller through the application of water atomizers at their exhaust ducts." Parnell [1994] provided photographs to the Congressional Subcommittee illustrating the apparent coagulation of grain dust in the basement and other locations of a grain elevator where water fogging nozzles were being used. He provided a dramatic visual demonstration of the decrease in the dust concentration. It is likely that an electrostatic attraction of dust and water droplets results in coagulation causing the larger droplets to settle by gravity. Particles of less than 10 micrometers have a settling velocity of 0.6 feet per minute [Cooper and Alley, 1994]. Without significant coagulation, the grain dust particles would not settle out.

In the report by Allison [1993] "Effectiveness of ultra fine water fog as a dust suppressant", nozzles of 0.008 inch and 0.020 inch diameter were used at pressures of 800 to 1200 psi to create a fog-like mist at typical transfer locations in an elevator were dust is generally

emitted. The nozzles, creating negatively charged water particles less than 10 microns in diameter, were set to create a fog whereby they would be attracted to positively charged dust particles less than 10 microns in size. As the fog and dust particles come in contact, they coagulate causing the dust to slowly settle out. In many of the transfer point applications, less than 25% of the water applied ever reaches grain surfaces. Because the fog particles are so small, very little water is actually used. In one scenario of operation at the truck dump, boot of bucket elevator, and head of bucket elevator, a total of 0.022% water mist was applied for effective dust control. In a second scenario, water mist was applied at a truck dump, boot of bucket elevator, head of bucket elevator, belt out of a garner bin, and at the tripper into storage bins; for a total of 5 applications with a total of 0.054% water applied. In a third scenario, water mist was applied out of storage bins going onto a belt, at the boot of a bucket elevator, at the head of the elevator, and at rail load out; for a total of 4 locations and a total of 0.015% water applied. If the last two scenarios were combined a total of 0.069% water could have controlled dust for the entire time in the elevator. Even with $3.00/bu corn, the added weight value of 0.069% is about 0.207 cents/bu; with soybeans priced at $6.00/bu, the added weight value is about .41 cents/bu. The mode of operation with a fine-particle spray mist is more of a treatment of the air space where dust accumulates, which is different than using the low pressure, high volume nozzles that coat the surface of grain to help dust particles stick to the grain.

Cost Comparisons.

The operational costs of adding water or oil to grain is a fairly simple calculation. However, the operational cost of operating a dust control system in units of $/1000 bu is complicated. Cost per bushel is a function of the total volume rate of flow of all the dust control systems used at a specific elevator and their respective fan total pressures, maintenance costs and costs of disposing of dust collected and not added back to grain. Data from the study on recombination/recirculation dust [Parnell et. al., 1992] were obtained from an on site study of 7 export elevators that had an average throughput ranging from 40 to 470 million bushels per year. The number of dust control systems ranged from a low of 7 to a high of 52 (average=32). The average volume rate of flow ranged from 11,000 to 25,000 cfm per dust control system. The calculated average air flow per 1000 bu ranged from 1.1 to 6.1 cfm 100 bu. The 6.1 cfm/1000 bu. was found to be the smallest export elevator studied. In the opinion of the author of the study, 5 cfm/1000 bu would be a good estimate of the volume used by all elevators that have a volume exceeding 2 million bushel per year. All smaller elevators will have at least 20 cfm/100 bu.

The operating costs of pneumatic dust control systems are the sum of; 1) electrical energy used; 2) disposal of captured dust; and 3) maintenance costs. Consider the following model: 1) electrical - $4.50/1000 bu. [Parnell, et. al., 1992]. This number is the average of all 7 elevators with electrical costs ranging from $2.92 to $8.34/1000 bu.; 2) disposal cost - $0.50/1000 bu. The average dust captured by elevators in the study if they returned no dust to the grain was 3.2 pounds per ton or 96 lbs/1000 bu.. At $10/ton disposal cost, the disposal cost would be $0.48/1000 bu.; and (3) maintenance cost - $16.50/1000 bu. Assume a 33% capital cost as an estimate of dust control maintenance cost and $10 per cfm as the capital cost of dust control systems with bag filters -- 5 cfm/1000 bu. x $10/cfm x 0.33 = $16.50/1000 bu.

The sum of the three categories of costs described above is $21.50/1000 bu. This number is very close to the number provided by Walker and Associates of $20.20/1000 bu. In the opinion of Parnell et. al., the costs for installation for oil additive systems can range from less than $2,000 to over $30,000. At the extreme one operator reported installing an oil additive system that consisted of pumps, barrels and spray nozzles for a cost of approximately $500.

Operational costs for each of three alternative systems for an elevator handling 1 million bu./month are approximately:

pneumatic:	$20.20 per 1,000 bu
oil:	$ 3.58 per 1,000 bu
water:	$ 0.04 per 1,000 bu

Installation costs for an elevator handling 1 million bu per month are in the range of $30,000 for either oil or water systems; $44,000 for a combination oil or water system; and $250,000 - $300,000 for an aspiration system. [Walker and Associates, 1993].

The application rate of food grade mineral oil to grain is limited by FDA to less than 200 ppm (1.5 gallons per 1000 bushels [Food and Drug Administration, 1982]. The cost of mineral oil is $2 to $3 per gallon. The relative price of soybean and mineral oil change with market conditions.

Analyses on the Financial Impact of Water and Oil Dust Suppressants on Soybeans has been documented as supplementary information regarding the FGIS final rule prohibiting the addition of water to grain. Table 5 presents these data.

Industry representatives have presented the results of studies completed by the American Feed Industry Association (AFIA) and the Grain Elevator and Processing Society (GEAPS) concerning feasibility of meeting the permissible exposure limit (PEL) for oat, wheat, and barley grain dust set by the California Occupational Safety and Health Standards Board. Evaluation of the results of these studies by industry representatives concludes that compliance with the PEL standard of 4 milligram per cubic meter would represent economic hardship for members of their industry. Food and Allied Service Trades provided the following analysis of the costs associated with meeting these standards in one of their facilities [Mestrich, 1993].

"Following our review of the industry supplied cost studies we contacted Airtech Industries for an independent cost estimate. Airtech told us that they could fit the said facility with a comprehensive dust collection system that would enable the facility to comply with the 4 mg/m^3 PEL. We were quoted a total price of $64,398 ($53,052 in 1988 inflation adjusted dollars) to install the system. We note that this is almost $10,000 less than the 1988 AFIA estimate of $73,500. Moreover, our estimate is almost $20,000 less in constant 1988 dollars. Finally, our cost estimate assumes that no other existing dust control mechanisms exist in the facility. Since all facilities currently have to control dust levels to comply with other OSHA standards, we assume that facilities have implemented control systems that will obviate the installation of a complete system overhaul." [Mestrich, 1993]

Dust emission standards set by EPA and Department of Environmental Quality (DEQ) also impact vessels during loading or discharge at U.S. ports. When these standards were implemented all of the export elevators in the Pacific Northwest put in evacuation systems to take the dust particulates out of the air. The cost is borne by the vessel that receives the cargo. The secretary-treasurer of the Supercargoes and Clerks, Local 40 explained the charges. "... the owner or the charter, whoever it may be, that receives that cargo pays, in effect, 35 cents per short ton, 35 cents per 2,000 pounds for that equipment. That is an elevator charge to the vessel that is loading there. That equates to $21,000 to a ship loading 55,000 tons of grain. At 100 ships a year, $2.1 million. Ten years equals $21.2 million that the elevator receives back from the vessel for that dust control system. It isn't water. It is a dust system that vacuums up the dust particulates in the air, puts them in a silo. Then trucks come to the silo. Hog ranchers receive that dust to feed their hogs with. So the elevator operators are getting money at both ends of that system." [Clark, 1993]. "However, the New Orleans Gulf (from where most of the grain is exported) does include a separate charge in their tariff. They have a total facilities use charge of 25 cents per ton." [Hawk, 1995].

It has been estimated that prohibiting the use of water for dust control would result in an increase in insurance costs of $6000 per year at an elevator handling an average of 1,000,000 bu/month. [Personal communication with Walker & Assoc.] In addition, the alternative of pneumatic dust control has been estimated to cost $5 to $10 per c.f.m. under the assumption that it would require from 10,000 to 20,000 cfm per grain transfer point. The cost of installing bag filters to comply with air pollution regulations could be as high as $100,000 to $300,000 per application point. Elevators with pneumatic systems already installed would not incur the entire cost.

Economic Impacts.

The economic impact of a prohibition on the use of water for dust suppression in grain handling facilities will depend on many factors -- current practices at these facilities, volume of grain, and the direct and indirect costs of each alternative system that have been described in the previous section. Most of these costs can only be estimated and aggregating across all firms in the industry would require extensive and detailed data that are not available.

One piece of information needed for estimating impact is the current use of the different technologies including water application. A survey conducted by the University of Illinois provided estimates of the frequency of the different technologies and the motivation for their use. A survey was mailed to approximately 2500 grain handling firms throughout the United States asking for answers to the following questions: (1) What methods are currently being used by grain handling firms to control dust? and (2) What is the primary motivation for implementing dust control strategies? (3) What are the marketing practices that encourage or discourage the application of water to grain? A survey form was mailed to approximately 2500 grain marketing firms. Thirty-eight of the 2500 were returned as undeliverable or were not handling grain. Six hundred and seventy-one responses were received from the remaining firms. However, not all respondents answered all questions. The number of responses for each question was used in calculating percentages. Also, some respondents answered for multiple firms and firm types in the company. Multiple firm types on one survey were included as one answer in calculating percentages for all firm types. They were counted as multiple responses when analyzing the data by firm type. The sum of responses by type of firm will, therefore, exceed the total.

Results of the Survey

Responses were received from 36 of the 48 continental States. The majority of responses were geographically concentrated in the corn and wheat belts. Respondents were asked to classify their firms as country elevator, river elevator, inland subterminal, feed manufacturer, grain processor, or flour miller. the majority of the respondents were country elevators (Table 6).

Dust Control Techniques. Respondents were asked to indicate the methods used to control dust in their facility. Regular housekeeping, sweeping, etc. was reported most often (89.9%) (Table 7). Over half used aspiration or pneumatic devices to control the dust (53.8%). Other technologies included oil application (42.9%) mechanical devices (37.9%), and water application (7.6%). Dust control differed among firm types. The use of water was reported most frequently by flour millers (17.6%) and the inland subterminals (11.8%). Aspiration, used by 5.3% of all respondents, was reported more often by flour millers, river elevators, and export elevators than by country elevators. The use of oil was reported by 60.7% of the export elevators but by 23.5% of the flour millers who have often reported potential carryover of oil additives into the flour.

Motivation for Implementing Dust Control Strategies. Dust control methods are used to achieve multiple objectives. Respondents were asked to indicate the relative importance of various possible motives for implementing dust control strategies. A value of "1" indicated "very important", "2" indicated some importance and "3" indicated "minor importance". Respondents were asked to rate, not rank, the motives so the same score was often given to more than one motive and the percentages sum to more than 100 percent. Blanks were not counted in the scoring. The primary motive for using dust control strategies reported by all respondents was to reduce the danger of dust explosion (84.7%) (Table 8). A number "1" rating was also given to meeting OSHA standards by (54.7%) of respondents; meeting EPA standards by (53.7%); meeting company housekeeping standards by (52.3%). Thirty-two percent stated their primary motive was lowering their insurance rates. There was no consistent pattern among the firm types. Dust explosions were given as the primary motive more frequently by export elevators (95.8%) and inland subterminals (93.1%). The export elevators were less influenced by insurance rates associated with dust control than any other firm types (10.5%).

Base Moisture Levels Used in Buying Grain. The economic incentive for using water to increase the weight and moisture content of grain originates with grain whose moisture content is below the base. Since moisture content is no longer a grade determining factor the market is free to select the base moisture content for quoting prices. The base varies among the four major grains, but also varies among firms.

Three fourths of the respondents reported a using base of 15.0% moisture for corn (Table 9); 16.9% of the respondents used 15.5%. The most common base moisture for firms purchasing wheat was 13.5% (69.4% of respondents); 20.1% of the respondents reported a base of 13.0% moisture. Over 90% of the respondents used 13% as the base moisture for soybeans. A base moisture of 14% for sorghum was reported by over 80% of the respondents.

The base moisture used for soybeans is similar across all the firm types except for the export elevator. The export elevator reported a higher base moisture for soybeans (14%) than the other firm types (13.5%). [Hill and Caponigri, 1995]. For corn, a base moisture of 15% was reported by three-fourths or more of all firm types except four millers (33.3% and river elevators (72.2%). River elevators tended toward higher base moisture -- 20.3% reported a base moisture of 15.5%. Only 10.5% of export elevators reported 15.5% as the base -- 5.3% reported a base of 14.5%. The moisture content used as a base for wheat was similar for all firm types, although the river elevators tended to quote a lower base more often than the other firms. The base quoted for sorghum is similar for all the firm types.

These data indicate that prohibiting the use of water for grain dust suppression would affect a relatively small proportion (7.6%) of the firms handling grain. The impact will be greatest at the export and subterminal elevators and least at the country elevator. The examples of costs of alternative methods provided in this report can not be generalized to all of the firms that reported use of water for dust control, but only indicate the range of values for the alternatives currently being used in the industry.

Regulation of Alternative Technologies.

There are two major obstacles to the enforcement of a prohibition on the use of water whether based on the FDA ruling or the FGIS ruling. (1) The prohibition is based on motive. (2) The prohibition is tied to the process not to the effect on end product.

Motive is extremely difficult to establish except in extreme cases. Farmers and elevator operators may have multiple motives. Aeration and blending are good strategies for storing and marketing grain. However, both alter the moisture content of the grain and thus change its weight and value. Grain is hygroscopic and will naturally gain moisture with increases in relative humidity and lose moisture with decreases in relative humidity. For example, the equilibrium moisture content (EMC) of shelled corn at 50 ^{o}F and 50% RH is 12.2% wet basis (wb). The EMC at 50 ^{o}F and 90% RH for this same shelled corn is 21.8% wb [ASAE, 1994]. Moisture contents of grain in equilibrium with these two diverse environments could differ by 9.6 percentage points. The principles that control weight gain due to changes in moisture are the same whether achieved by grain elevator operators or producers trying to manipulate weight and value, or a phenomenon occurring naturally during the transfer of grain from one point in the market channel to another. There are no tests capable of differentiating between shipments in which the shipper has added water and shipments where environmental conditions altered the moisture content and weight. However under the previous allowance by FGIS, the customer receiving grain at higher than expected moisture contents, or grain that has gained weight during shipment, would be inclined to believe that water had been intentionally added.

The potential weight gain from the addition of water is small if the application rate is limited to 0.3%. In a 50,000 mt shiplot of wheat, the application for dust control would add 150 mt. At a price of $128 per mt the water would add $19,200 to total receipts -- $0.38 per ton or $0.01 per bushel. Total increase in value would be $33,066 -- $0.018 per bushel for $6.00/bu

soybeans. Given the low profit margins in the grain export industry this is still a significant incentive.

The potential economic benefit to an elevator from the addition of oil is much less. For example, by applying mineral oil at a 0.02% rate to a 50,000 mt shiplot of wheat, an exporter could add 10 mt of oil (2,857 gallons) to the shipment. If the wheat was sold for $128 per mt, the oil could generate over $1,280 in additional profit for the shipper. However, the 10 mt of oil (at $2.00 per gallon) would cost the shipper $5,714. As a result, the shipper in this example would lose over $4,434 by applying oil at its recommended rate. [Galliart, 1993].

Total application rates of 0.3% will be difficult to monitor by FGIS. Wide fluctuations in grain moisture content as a consequence of absorption of water from ambient air could incorrectly suggest that an elevator had exceeded the water-added allowance when in fact it had not.

It has been suggested that FGIS could establish a permit or licensing program to monitor and control water applications. FGIS concluded the process would not effectively prevent misuse and would create economic incentive for all companies to apply water whether or not it was needed for dust suppression. Effectiveness of a permit system is compromised because FGIS cannot rely on after-the-fact testing to verify proper application. It is technologically impossible to test and distinguish naturally occurring moisture from applied or added moisture. While FGIS could evaluate and license the initial system and approve installation, opportunities to override computer monitoring would exist with increased incentives to exploit any loopholes. Follow-up audits of systems would be time-consuming, expensive and minimally effective. Monitoring would require that FGIS shift from the current philosophy of proving intent to increase weight, to a philosophy of proving intent to alter an approved system. [Galliart, 1993] FGIS has estimated that the annual cost of a permit system would quickly exceed $1.5 million as more and more elevators are economically forced to apply water under the premise of dust suppression.

The Office of Inspector General also discouraged the use of a permit or license system. "Our investigations have disclosed that normal and routine monitoring of water-based systems, as would be done by FGIS, the Agricultural Stabilization and Conservation Service, or other Government agencies as designated, is not sufficient to protect the Government or grain purchasers from those elevators determined to use water to artificially increase moisture and grain weight. Some elevators have taken measures to conceal the water system, which leaves it undetectable by normal procedures and observation. .. As for the sophisticated, computer-controlled water systems, they are also vulnerable to deliberate misuse. Indeed, the intentional misuse of water by way of the computer-controlled systems is even more difficult to detect. Investigation has disclosed that computerized water control programs are being overridden. The amount of water showing on the monitor may not be the same as is actually being applied. .. Furthermore, grain belt sensors may be adjusted to provide a false reading of grain depth on the belt, which allows for the addition of more water than normally would be required for dust suppression. ..Investigation has disclosed that water applied to grain in layers on belts results in grain not going through the diverter sampler as intended by the manufacturer upon installing the sampler, and the samples taken do not reflect the actual quality of the grain. With the use of water, foreign material adheres to the grain and does not go through the separation devices;

therefore, it is not being read as foreign material. Manufacturers of diverter samplers have informed us their samplers are designed for used with free-flowing dry grain. The samplers are not guaranteed to give accurate measurements for wet grain." [Gillum, 1993].

The effect of rewetting on the accuracy of the moisture meter reading has also generated controversy. Most research shows that the meter reading is temporarily biased upward during a period of water absorption. However, the dielectric response returns to normal within a few hours, depending on temperature, environmental humidity, and average moisture content. [Bloome et al., 1982]

MONITORING THE USE OF WATER ON GRAIN

The issue of adding water to grain is much broader than just its effectiveness in controlling dust or preventing dust explosions. One of the primary concerns voiced during the hearings on prohibiting the addition of water was the fact that it could be used to increase the weight and deceive the buyer, particularly in the international export market. The FDA prohibition on the use of water specifically referred to use of water for the purpose of increasing its weight or to make it falsely appear to be of greater value than it actually is. [Food and Drug Administration, 1979]. It is important to evaluate the validity of these concerns and the feasibility of monitoring the industry to prevent the use of water to falsify weights and moisture meter readings.

The appearance of greater value would be possible only if the moisture meter is biased downward on rewetted grain or if the water is incorporated without the buyer measuring the moisture content. Since nearly all grain is sold on the basis of weight and a moisture meter reading at origin and/or destination, the deception could not be the result of failure to measure. The only source of deception would be an incorrect measurement of moisture. Most research shows that the meter reading is temporarily biased upward during a period of water absorption. However, the dielectric response returns to normal within a few hours, depending on temperature, environmental humidity, and average moisture content. "At low grain temperatures and/or when larger amounts of water are added, longer waiting periods are required before indicated moisture content approaches true moisture content. Warm wheat absorbing 2 percentage points may require less than 1 hour, while wheat with temperatures near freezing absorbing several percentage points may require as much as 24 hours" [Bloome et al., 1982].

The primary incentive for adding water derives from a market pricing system where the price and quantity have not been adjusted to accurately reflect the differences in dry matter contained in grain at different moisture contents. Grain at moisture levels below the base (15.0% in the case of corn, 13.0 % in the case of soybeans, 13.0 or 13.5% in the case of wheat) provides the opportunity for economic gain by adding water. If the price per ton or bushel is the same for 14% moisture corn as it is for 15% moisture corn, and no adjustment is made for the dry matter per ton, there is a strong incentive to add moisture to bring the 14% corn up to 15%. The market is offering to pay corn prices for water.

However, if the water is added after the grain has been weighed, there is no impact on the contract weight which is the basis for payment. If the water is added before final weighing, the sample measurements will still indicate to the buyer the actual quantity of dry matter or the equivalent weight at contract price. With accurate information about quantity and moisture content the buyer cannot be "deceived". If the moisture content exceeds the contract moisture, the grain would normally receive a discount, or be certificated as failing to meet the contract, or FGIS would require that that sublot be unloaded.

It is important to establish the source of the concern of the foreign buyer. Water cannot be added without being reflected in the moisture reading or the weight or both. An increase in the moisture content would also violate the contract, unless the moisture content of the grain is below the contract moisture. Moisture content of grain is often below the maximum limit specified in the

contract. Under this condition, the complaint that the buyer has been deceived or cheated must be based on an expectation by the buyer of receiving better quality than was requested, e.g. receiving 14% moisture (86% dry matter) corn at the price negotiated for corn with 15% moisture (85% dry matter). It is unclear in this example whether the buyer or the seller has been disadvantaged.

The use of water to suppress dust in grain elevators is a technology that could provide a low cost method of reducing dust emissions to comply with air pollution regulations and prevent dust explosions. If properly done the impact on grain quality will be minimal, the weight of the water will be included in the weight of the grain on the scales and the moisture determination will correctly identify the percent of that weight which was water and that weight which was dry matter.

In the Congressional Hearings the difference between the house and the senate versions of proposed legislative controls was the belief that the application of water could be monitored by FGIS and those elevators improperly applying water could be identified and prosecuted. The OIG maintained that there will always be a way to bypass the monitoring system, while some researchers and some members of the grain industry claimed that a system could be developed that would be foolproof.

The pros and cons of the enforcement of a rule promulgated by FGIS that would allow for a total application rate of 0.3% of water for the purpose of preventing dust explosions or complying with air pollution regulations are as follows:

(1) A permit system can be established whereby advance approval by FGIS must be obtained prior to installing a water application system. The permit would have sufficient engineering description of the application system such that an FGIS engineer could insure that the system would function to either prevent dust explosions or assist in complying with air pollution regulations. Reporting requirements could be included to insure that the system was not being used to manipulate the marketing system prior to approving installation. Enforcement of violations could be included for those facilities who had exceeded allowed moisture additions based upon entering and exiting grain moisture contents. This concept is similar to the permitting and enforcement rules associated with regulating air pollution in most states. For example, more than 25,000 facilities have permits and are subject to enforcement in Texas.

PROS: A system of using water to make elevators safer would be available.

CONS:
(a) FGIS would have to hire more staff to handle the permitting and enforcement functions. Most of the additional permitting staff would have to be qualified engineers. FGIS suggested that they would have to place an employee in every elevator to insure compliance. FGIS has estimated that the cost of the permitting system would exceed $1.5 million/year.
(b) The cost of a water application system for an elevator would be increased by the licensing requirement in that it would have to include the

engineering specifications associated with approval of their permit application.

(c) The elevator would be required to submit reports to FGIS that would potentially subject them to fines and penalties.

(d) FGIS has not operated with a permit/enforcement system. This will be a new system for a regulatory agency and it would take time to implement.

(e) FGIS has had limited regulatory authority over country and inland terminal elevators in the past. This system would bring country elevators applying water application systems (through a permitting process) under the authority of FGIS which may not be popular.

(f) A system of fines and penalties will be required for those facilities who attempt to abuse the system.

(g) Overseas customers may claim that the quality of U.S. grain is reduced because we are allowing the application of water to grain.

(h) FGIS would still need to prove the source and intent of any increased moisture content.

(2) Some have suggested that the marketing system has an inherent safeguard against abuse. If an elevator were to add water using a fire hose, the grain quality would rapidly deteriorate. Hence, as the grain progresses through the country elevator to the inland terminal to the export, this high moisture grain would be detected and the abuser identified. This concept recognizes that grain must be kept below specific moisture contents in order to prevent quality deterioration: 14% wb for field grains and 11% wb for oilseeds.

PROS:

(a) The bureaucracy associated with a permitting system operated by FGIS would not be needed.

(b) The use of water for dust suppression would be less expensive.

(c) The marketing ability of abusers would be impacted by inland terminals and export facilities not purchasing grain from this location.

CONS:

(a) There would be allegations of wide spread abuse (adding water for economic gain).

(b) There would be an incentive to add water to low moisture grain beyond the proposed 0.3% level.

(c) If an abuser is identified, proof of intent would be required and may be difficult.

(d) If the perception that a grain elevator's competitors are abusing the system by adding water, there will be an incentive to abuse the system to meet the competition.

(3) Some have proposed a computer controlled water application system that would allow for monitoring to prevent abuse. This system would prevent the over-application of water to grain. One commercial vender offers such a system.

PROS:

(a) This method would allow for the use of water without the cumbersome bureaucracy of FGIS implementing a permit system. It would, however, require FGIS grant approval to the elevator prior to installation.

(b) The engineering associated with such a system would have to be a quality process eliminating the simple systems that could be used to easily abuse the application of water to grain.

(c) FGIS could control the number of elevators adding water to grain by only approving systems that had been approved in advance.

(d) Only systems that had been thoroughly reviewed by FGIS would be approved.

CONS:

(a) Irrespective of the engineering safeguards, any system can be circumvented if the operator of the system wants to abuse the addition of water to grain. Hence, enforcement would require periodic checks to see if the grain elevator operator is complying with the imposed application limit. Fines and penalties will have to be developed for those facilities who purposely or inadvertently add too much water to grain.

(b) No regulator agency should be in the position of recommending a vendor. There will be the potential of approving a system that is supplied by a single vendor.

(c) The monitoring process would have to be developed to insure that the system is working properly. One control strategy is to monitor and report the total water used. An alternative system would require the elevator to report moisture contents of all incoming and exiting grain and require that no grain leave the facility with moisture contents higher than the safe storage moisture content of that grain.

<u>Summary of Monitoring Strategies for the Use Water for Dust Control</u>

The use of a rule/permit enforcement system to monitor the application of water to grain is technically feasible. A similar system is currently being used by air and water quality regulatory agencies. However, it would require an expanded role of FGIS and require a significant increase in resources for the agency. In this time of reduced federal funding, the resources may not be available.

The concept of using the marketing system as a self regulatory process and limiting the water application rate (by rule) to no more than 0.3% by weight has merit. It may be possible to include in the rule-making that any grain leaving an elevator that is using water for dust suppression will be given a limit on the moisture content of grain to be marketed. This system would allow for regulating grain quality without having to prove intent. If an elevator using water, allowed grain to leave the elevator with a moisture content in excess of that allowed by rule, penalties would be levied irrespective of the source of moisture. This strategy would be difficult to apply at facilities other than export. Processors and country elevators often receive or ship grain at moisture levels too high for safe storage. Limits on moisture content at any point in the market channel will restrict the free operation of the market to choose quality based on price and value.

The proposal to allow the use of computer controlled equipment to insure that no more than 0.3% water is applied to grain would be difficult to implement without recommending a vendor. In addition, equipment can fail and an inadvertent application of water to grain could occur. A combination of equipment and some form of regulation on maximum moisture content could be implemented.

The FDA regulation and the 1987 ruling by FGIS requires that regulators determine if the moisture content of the grain has been changed in a manner that violates the law. Enforcement is extremely difficult because prosecution of violations must prove motive. In some situations the violations are obvious and the intent to defraud is readily established. FGIS investigators reported several instances of clear violations. "Our task force discovered the use of fire hoses to apply a steady stream of water to grain on conveyor belts, elevator legs, and in elevator spoutings." At one facility "the water pipes were in a false grain chute, entirely there for concealment purposes. ... We also repeatedly found dust suppression systems misused. Application points at the critical dust control points such as the bottom of a truck dump before the grain is elevated into the house, the nozzles were nonfunctional and the pressure was disconnected and the pipe was not even inserted into the system". Other examples are available [Stang, 1993]. Another example of the difficulty of proving intent is provided by a case in Nebraska, where in August, 1992, the USDA inspector general and Nebraska authorities raided a grain company and found a hose rigged to pure water onto a belt carrying grain. However, the chief operating officer testified he was adding water to control dust, and a federal grand jury in Omaha did not indict the company for economic adulteration because intent could not be proved. [The Wall St. Journal, 1993]

Motive and intent is even more difficult to establish from data on changes in moisture content. FGIS investigators reported the results of monitoring inbound and outbound moisture levels of grain at a country elevator for a period of three months. The moisture content of the grain received during the three-month period averaged 13.5%. The average moisture of grain in outbound railcars was 14.5% to 15.0%. The 1 to 1.5 percentage point increase could have been the result of water added by the elevator. However, there are numerous other equally plausible explanations which would not have been illegal under either FDA or FGIS regulations. Possible explanations include: (1) aeration to control temperature and insects, (2) blending 16% moisture grain with low moisture inbound grain, (3) the cars loaded out may have been selected from higher moisture bins and grain with below average moisture was still in storage, and (4)

differences in the bias of different moisture meters (some elevators use state-approved meters on inbound grain and the official FGIS meter on outbound grain).

There are other causes of increased moisture content in grain. Handling cold grain from northern origins in the warm, high humidity conditions found at the gulf ports, will result in an increase in moisture through absorption or through condensation on the surface of the kernels. In an environment of 50 F and 40% RH corn has an equilibrium moisture content (EMC) of 11.2%. In an environment of 60 F and 65% RH the EMC is 14.8%. In an environment of 80 F and 90% RH the EMC is up to 19.1%. Grain must be exposed to this environment for an extended period of time to reach this equilibrium. The rate of moisture absorption will depend on aeration airflow and the temperature of the air. Air at 80° F would be expected to transfer moisture much faster than air at 50° F. An airflow rate of 1 cfm/bu will change temperature 2 times faster than an airflow of 0.05 cfm/bu. While the equilibrium moisture data illustrate a potential for a significant change in moisture content during transfer from a midwest elevator to a gulf port elevator or through aeration, it could take 120 to 240 hours of aeration to achieve that magnitude of a change in moisture contents, using airflow rates of 0.1 to 0.05 cfm/bu, respectively.

Other reports have demonstrated that increases in moisture content of grain frequently occur during transfer between two points in the market channel. Wade and Christensen [1977] reported, "Corn weight increased 0.1 to 0.5 percent from condensation during aerating with ambient air. Similar conditions occur at southern U.S. terminals which may cause gains over 0.1 percent as grain is exposed during handling." [Wade and Christensen, 1977].

More than one heat and mass transfer mechanism is at work in the absorption process. Movement of moisture between air and grain is driven by differentials in vapor pressure. Equilibrium is achieved when the vapor pressure within the grain kernel is in equilibrium with the vapor pressure of the air. If grain is exposed to air with a particular vapor pressure for a long enough period, it will come to its equilibrium moisture content, either by gaining or losing moisture.

When grain temperature is below the dew point of the air, moisture will condense on the grain just as it does on the surface of a glass of ice water. The condensate is then absorbed into the grain. Anyone who has watched cold or frozen grain being unloaded from a barge in a Gulf port will testify that this is dramatic. As the water vapor changes state it releases heat that warms the grain. The process will continue until grain temperature exceeds the dew point of the air. However, it is limited by the amount of air that contacts the grain during high capacity grain movement.

When grain is cooled by aeration, moisture is removed. When grain is warmed by aeration, moisture is restored to the grain. Foster [1967] alternately cooled and warmed wheat samples between 50 and 80° F by aeration. Moisture reduction during cooling averaged 0.47 percent while moisture increase during warming averaged 0.58 percent. These moisture changes occur rapidly, with the passage of the cooling or warming front, and are, in normal temperature, humidity, and moisture content ranges, independent of the relative vapor pressures of the air and

grain. After aeration cooling or warming has been completed, any further moisture transfer will be driven by the differential in vapor pressure.

Moisture transfer due to vapor pressure differential is much slower than moisture transfer due to temperature differential. Raising the moisture content of grain by aeration with moist air requires days and weeks and will normally not pay the power cost of aeration except in shallow grain depths. In contrast, warming grain by aeration requires less time and the returns in increased sale weight can be 10 to 20 times the cost of aerating.

The moisture content of grain may be altered in many ways and for many different reasons.

1. Direct application of water through spraying, fogging or misting.

2. Aeration of grain when the ambient air has a relative humidity content above the equilibrium relative humidity of the grain being aerated. The rate of absorption of moisture during aeration depends on several factors including air and grain temperature, air flow, genetic make-up of the grain, and previous drying and storage history.

3. Blending dry grain with grain of higher moisture. This is an essential management practice at all elevators, including dumping grain from any two trucks into the same bin, unless both trucks contain grain with identical moisture contents. Grain of different moisture contents will equilibrate in a relatively short period of time when uniformly blended. The equilibration process results in moisture from the wet kernels moving to the dry kernels [Hill and Wei, 1993].

4. Loading grain during periods of high humidity, including during a rain storm. Moisture absorption from humid air is relatively small if the grain is exposed to the humid air for only a short period during loading or belt transfer.

5. Selecting the time of day for harvesting. Grains (especially soybeans) change moisture rapidly as temperature and humidity change in the field. It is not unusual for soybeans to gain 1 or 2 percentage points of moisture from high humidity air during the night, and then lose that moisture the following day. Farmers can "add" moisture to soybeans by choosing to harvest in the early morning hours instead of late afternoon. The end product of this process cannot be distinguished from a similar result using aeration.

6. Seasonal changes while the grain is in the field. Changing weather conditions result in an increase and decrease in moisture content of grain many times between maturity and harvest. The drying process from physiological maturity to harvest moisture is not uniform.

None of the changes in moisture content described above are illegal, unless the motive is to "increase its bulk or weight, or reduce its quality or strength, or make it appear better or of greater quality than it is". [Food and Drug Administration, 1979]. However, FDA continued to assert that any method for increasing moisture was illegal if the motive was to increase the weight or value of the grain. "We hold this position regardless of how the water was added and regardless of who adds it. Aeration of wheat during humid periods for the purpose of increasing its bulk or weight in order to maximize profits is not acceptable and is illegal for reasons outlined above" [Hile, 1981].

The use of aeration presents a particularly ambiguous situation for enforcing a prohibition. Multiple motives are usually involved.

Sentry Technologies (Chanhassen, MN) has developed an aeration controller which is designed to operate fans on grain storage bins to minimize temperature differences between stored grain and the outside air. By minimizing temperature differences, it is possible to prevent moisture migration which otherwise leads to spoilage in storage. The controller also measures outside air relative humidities. Since grain is a hygroscopic material, it will reach a moisture content that is in equilibrium with the temperature and relative humidity surrounding the kernels of grain. The aeration controller is programmed with equilibrium moisture contents for 20 grains, including corn, soybeans, wheat and sorghum. The operator selects the desired bin moisture content, then the type of grain, and the airflow per bushel provided by the aeration fan. Every 15 minutes, the controller calculates a 21-day moving average outside air temperature which is set as the target temperature for the grain. Then, if the present temperature will move the grain temperature closer to the target temperature and if the present relative humidity and temperature conditions create an equilibrium moisture content that is near the center band of the desired moisture content, the fans will be turned on. Every 15 minutes for 24 hours per day the decision to turn fans on or off is re-evaluated by the controller. Farmers are using aeration to increase moisture content of grain and FDA is not taking legal action [Stout, 1995].

The target moisture is applicable whether the moisture content is above the base or below the base moisture set by the market. In the rewetting mode fans operate when outside air conditions create an equilibrium moisture that is higher than the center band of the desired bin moisture content. In the drying mode, fans operate when outside air conditions create an equilibrium moisture that is lower than the center band of the desired bin moisture content. [Sentry Technologies, 1994]. One of the other cited advantages of this system is that insects like "stale" air. With fans starting at frequent intervals, there is less opportunity for "stale" stagnant air which helps to reduce insect activity. Thus, good management strategies for managing stored grain may inadvertently increase the moisture content of overdried grain. The effect from the point of view of the buyer, is the same as a deliberate attempt by the seller to increase the weight by adding moisture. Even without the sophisticated controls, aeration of grain in storage is recommended. If the fans are run continuously, the moisture may be increased and decreased several times during a storage season.

The incentives for adding water to grain come primarily from the opportunity to return over dried grain back to the base moisture set by the market. Dust control may be less important

than the economic incentive of increased weight, especially at the farm and local elevator. FGIS permission to use additives for dust control tied legality to motive and generated the potential for marketing firms to abuse the intent of the regulation. That abuse was the primary justification for Congressional Hearings and the eventual action by FGIS to prohibit the use of water regardless of intent.

Enforcement of the prohibition by FGIS and FDA has been difficult. FDA's stated policy was that "We will consider regulatory action in those cases where there is evidence of consumer deception or of a safety problem arising from the addition of moisture to grain" [Hile, 1985].

Only one instance of an attempt to enforce the FDA ruling has been found. In 1983 a farmer in Kent County, Michigan was accused of delivering corn that had been rewetted to the Commodity Credit Corporation. The warehouse which accepted the corn notified the Michigan State Police, who in turn notified the FBI. The Office of the Inspector General was then alerted. Records do not show any final action and OIG does not record any subsequent prosecution. [Michigan Farm Facts, 1983.] Officials in FDA have no records or memory of any investigations or prosecutions related to the prohibition of adding water to grain, based on the FDA regulation. [Perrett, 1995] In fact, in 1987, 5 elevators in the State of Washington were found to be adding water to grain being loaded on barges. The rate of water varied at three of the sites from 8 to 12 gallons a minute, while the other elevators estimated they added from 500 up to 5,000 gallons of water per bargelot. These findings were referred to FDA. "FDA advised us that this matter has come up several times over the past decade and they recently discussed it with headquarters. They believe that it is a definite violation if water is added to grain to increase bulk or weight. However, if water is being added for dust control, they do not believe that prosecution is feasible. FDA has not set limits for the amounts of water that can be added to grain for dust control. Since each of the elevators visited claimed that they were adding water to control dust, and since any other elevators we visit would probably make the same claim, we recommend that this case be closed" [Joyce, 1988].

Many farmers and country elevators continued to use water as a means of bringing grain back to the desired moisture content. Base moisture received a premium, either in the quantity purchased or the absence of discounts. The market incentives strongly favored grain at the base moisture and the market rewarded those who achieved that base moisture. Blending of wet and dry grain was inevitable and it was impossible to differentiate between blending for the convenience of handling (e. g. unloading two trucks into the same bin) and blending for the purpose of increasing the moisture content of the dry grain. As indicated earlier, blending wet and dry kernels results in moisture moving from the wet kernel into the interstitial air and from there being absorbed by the dry kernels. The process is the same as aerating with high moisture air.

PRACTICES IN OTHER COUNTRIES

To compare the recent U.S. legislation prohibiting the addition of water to grain with regulations in other countries, representatives from government agencies and industry were contacted in Australia, Argentina, France, U.K., Canada, and South Africa. Information from each country was collected to document whether they allow the use of water as a dust control method.

Policies related to dust control in Australia were obtained through personal contacts who pursued these issues with representatives of the Australian Wheat Board (AWB). There are no regulations that prohibit producers or private grain handlers from adding water to grain, the AWB prohibits application of water for marketing purposes. With a moisture base of 14%, there is little incentive for producers to add water and little opportunity for commercial handlers to add water. The AWB limits the moisture content of wheat accepted into storage to 12% moisture, which discourages the addition of any water to wheat by producers. Wheat is also handled fewer times than in the United States, resulting in less dust creation [Batterham, 1995]. The AWB follows a detailed set of regulations and practices to reduce the danger of dust explosions.

Argentina has no regulations concerning the addition of water nor any provisions for use of water for dust control. Base moisture for corn is 14.5 percent and higher moisture levels are not accepted in the marketing channel. There is little opportunity for economic gain through the addition of water [Gutierrez, 1995].

It is strictly forbidden to use water on grain in France, although it is possible to use food quality vegetable oil on grain for dust suppression. There is a scale of premiums and discounts for grain moistures (around 14.5%) which also serves as a disincentive to add water to increase weight. If this system of premiums for corn below base moisture is used, it would be an effective deterrent to rewetting [Cordier, 1995].

The U.K. does not prohibit the addition of water to grain and does not consider the use of water to be adulteration, since water is already present in grain. Equipment to add water to grain is available for purchase in the U.K. However, the most common dust control method at country elevator and port locations is aspiration [McLean, 1995].

The European Union uses dry matter pricing when cereals are purchased by the Intervention Board. The Intervention Board limits the maximum moisture content for wheat, barley and rye purchases to 14.5% moisture. Bonuses are paid for grain purchased when the moisture content ranges from 10.0% to 13.4% [Intervention Board, 1993].

In Canada, the use of water on grain is prohibited in licensed elevators unless special permission is granted by the Canadian Grain Commission [Storry, 1995].

There is limited need to control dust in maize in South Africa. The dust control systems that are present are pneumatic methods. There is no regulation to prohibit the addition of water to grain, however there are maximum moisture contents of 14.0% for corn handled by the Maize

Board and 13.0% for wheat handled by the Wheat Board. In South African import contracts, there is a stipulation that they will not accept corn loaded from export terminals in the United States where the addition of water is practiced. There is no price adjustments for moisture content delivered below the base moisture content of 12.5% for corn and 12.0% for wheat [Cronje, 1995].

A MARKET DIRECTED SOLUTION

Enforcement of the prohibitions on adding water to grain have been selective at best. While many farmers and country elevators have used the technique to deliberately increase the weight or the moisture content, no systematic effort has been made to enforce the prohibition at these points in the market either through FDA or FGIS. Enforcement and supervision has been most aggressive at export elevators. It is anticipated that the current prohibition will also be selective in that the presence of FGIS in the export elevators will make it relatively easy to determine if water addition devices have been installed. Presumably only mechanical devices that actually expel water as a mist or fog will be enforceable. Strategies of blending wet and dry grain or aerating during humid conditions or even unloading barges during a rainstorm will not be enforced. Grain absorbs water from the ambient air whether standing in the field prior to harvest, during aeration in storage, or during transfer from one location to another.

In addition it will be impossible to enforce the prohibition in the large number of country elevators and farms that may use mechanical devices or any of the other alternative strategies for increasing moisture content. So long as the market is organized to pay grain prices for water added to grain below the base moisture, the economic incentives will make it extremely difficult to effectively and uniformly enforce a prohibition against the entire grain industry. Thus the question of equity will continue to be a point of contention within the industry.

The cost of enforcement can be reduced by eliminating the incentives. The incentives for illegally adding water (i.e. to increase its weight and moisture content) are entirely within the control of the market. Grain above the base moisture receives an explicit discount, generally in the form of a weight subtraction and a drying charge. Grain dried below the base moisture receives an implicit discount. Eliminating the implicit discount, removes the incentive for adding water to grain to increase its weight. The incentives for rewetting can be removed by calculating the quantity of grain for a market transaction on the basis of the weight of dry matter contained in the lot. The grain industry uses a shrink factor to adjust the weight of grain at moisture levels above the base, to the equivalent number of bushels at the base moisture content. Thus, the industry is using a concept of equivalent bushels at base moisture in order to adjust the weight of grain with excess moisture. The same formula and the same shrink factors can be used to adjust the quantity of grain at moisture levels below the base to the equivalent bushels at base moisture. The quantity purchased would be determined by the dry matter contained in the grain. This would eliminate all incentives for adding water since the seller would receive the same total dollars for 1000 bushels at 14% moisture as received for 1012 bushels at 15% moisture assuming no price adjustments for quality discounts. Quality discounts would be assessed independently of quantity adjustments. In addition, the FDA ruling would become irrelevant since adding water to grain would not increase its weight (as determined by the equivalent bushel formula) nor its market value.

Pro and Con of the Equivalent Bushel Approach

The logic to the use of equivalent bushels for calculating quantity is that it would allow farmers and elevators to select the moisture content that was best for their storage or handling practices without any penalty, it would eliminate incentives for rewetting, it would eliminate the

necessity for the policing action and budgetary implications for FGIS, and it would generate greater equity by paying all sellers according to the value of the grain and the product which they deliver. It would allow producers to dry grain to a safe storage level without penalty for selling grain below the base moisture at the time of delivery.

The advantage of the equivalent bushel concept is offset by several disadvantages.

1. Blending income derived from differences in moisture content would be virtually eliminated. Under the current pricing structure, grain above and below the base moisture level generates income to those who blend wet and dry grain together. Reducing blending income need not reduce elevator profits which are determined primarily by competition. Blending income changes when crop conditions change. Elevators adjust their margins to maintain competitive profits.

2. Farmers who over dry grain by accident or intent or who must harvest at moisture contents below the base will have a smaller implicit penalty under the equivalent bushel concept. This should not create an incentive for over drying however since harvesting soybeans at moisture levels below 13% increases field losses and drying corn below the base moisture increases the cost of drying.

3. Grain buyers will find it necessary to measure moisture content on every load, thus increasing the cost of marketing and quality determination. Under the present system, elevators may by-pass the moisture test if the grain is obviously below the base moisture.

4. Grain below the base moisture has a lower value than wet grain because it breaks more easily and may contain more broken kernels than grain stored at higher moistures. However, breakage susceptibility is influenced by genetics and drying method as well as final moisture content.

5. The basis for pricing and price differentials should be market determined, not dictated by regulatory agencies. Although the equivalent bushel does not prevent buyers from setting prices and discounts based on market conditions, it is viewed by some as regulatory interference in market operations.

6. The equivalent bushel concept will require calculations on dry grain as well as wet grain in order to determine the true quantity that is being purchased, increasing calculation costs. Shrink factors that are currently applied only to grain above the base moisture would need to be applied in a similar manner to grain dried below the base moisture.

This concept has been used in other countries and at one time was used in Canada for soybeans [Ontario Soybean Growers, 1983]. In addition, a survey of Illinois elevators in 1985 showed that 14 percent of the respondents were already using the equivalent bushel concept or were paying premiums for grain dried below the base. [Hill and Spangler, 1985]. A national survey of 1994 practices at grain handling firms showed 5.4 percent of the respondents were adjusting price or quantity of grain dried below the base moisture. The percent was higher for export elevators, feed manufacturers, and flour millers; lower for country and subterminal elevators (Table 10). [Hill and Caponigri, 1995]

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