

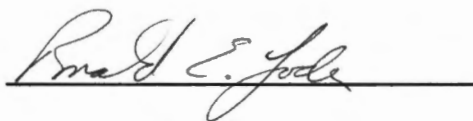
To the Graduate Council:

I am submitting herewith a thesis written by Sheldon D. Barker entitled "Struvite Control in Recycling Flush Systems Using Chemical Inhibitors". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering Technology.


C. Roland Mote, Major Professor

We have read this thesis
and recommend its acceptance:





Accepted for the Council:


Associate Vice Chancellor
and Dean of the Graduate School

STRUVITE CONTROL IN RECYCLING FLUSH SYSTEMS USING CHEMICAL INHIBITORS

**A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville**

**Sheldon D. Barker
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Abstract

Struvite is a mineral scale that forms in and on components of recycle flush systems, causing equipment failure. To date acid flushing is the most often recommended means of removing and controlling the buildup. As a part of an on-going project, this thesis tested a potential inhibitor, Kelig 4000, under field conditions. The use of an inhibitor to prevent, or slow, the formation of struvite is an attractive alternative to acid flushing for several reasons. Inhibitors reduce the time the recycle flush system is off-line for cleaning, and require less time of the producer. The use of inhibitors to control scale has been used in other applications, such as cooling towers and boilers.

The results thus far are promising. Suitable inhibitors have been identified, and Kelig 4000 has performed well under field conditions.

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1. Introduction

Specialization in the livestock industry has led to the confinement of livestock on small areas of land for several reasons. One, the producer has greater control over the management of the environment and health of the animals. Also, more animals can be produced on fewer acres. However where animals are concentrated, manure is also concentrated, leading to problems in handling and disposal. One method of handling manure is to flush the housing area with water and collect the manure in a lagoon. This method is an excellent means of controlling odor and maintaining animal health. Some systems recycle the liquid phase of the lagoon to reduce the amount of fresh water used and thus the amount of waste materials handled. Lagoon effluent contains many ions that have the potential to concentrate and form precipitates in the pipes and pumps of recycle systems.

Magnesium ammonium phosphate hexahydrate, commonly known as struvite ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$), has been identified as the primary precipitate causing problems by clogging pipes and pumps in flush systems. This problem has caused some set backs in the utilization of recycling flush system technology.

Proper planning and lagoon management are helpful in controlling the problem, and once the struvite has formed, flushing the system with acid is helpful in removing the scale. However, these solutions are often costly and time consuming and do not always solve the problem. Because of this, many producers are abandoning recycling and switching to the use of fresh water to flush barns. The use of fresh water greatly increases the total volume of waste to be handled and stresses the capacity of handling and storage facilities. Continually stressing the capacity of storage facilities increases the potential for water pollution.

Protection of environmental quality can thus be served by controlling struvite formation and making it feasible to flush manure with recycled water.

2. Review of Literature

Chemistry of Struvite and Lagoons

Struvite ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$) is a rare mineral found mostly in guano deposits and in urinary stones of animals and humans. Struvite is a white crystalline material that has a low solubility in water and alkaline solutions (Abbona and Boistelle, 1978). Abbona et al. (1982) found that solubility decreases notably for pH values above 7.5. By using improved numerical methods and computer modeling, Buchanan et al. (1994) found that the pH range at which struvite forms to be from approximately 7 to 11, with 9 being the pH of minimum solubility. This range is lower than that reported earlier by Booram et al. (1975), who suggested that the range was from 7 to 13 with 10.7 being the minimum solubility pH. Abbona et al. (1982) also found that struvite will not precipitate if the supersaturation ratio is less than 1.3. The supersaturation ratio is $\text{pIAP}/\text{pK}_{\text{sp}}$, where pIAP is the log of the ion activity product and pK_{sp} is the log of the solubility product constant.

Brown and LeMay (1988) defined the solubility product constant as "an equilibrium constant related to the equilibrium between a solid salt and ions in solution." This provides a measure of solubility for a slightly soluble salt and can be expressed for struvite as:

$$[\text{Mg}^{2+}] [\text{NH}_4^+] [\text{PO}_4^{3-}] = K_{\text{sp}}$$

Where: K_{sp} is the solubility product

$[\text{Mg}^{2+}]$ is the concentration of magnesium. The $[\]$ means the concentration of the substance ions inside the brackets.

$[\text{NH}_4^+]$ is the concentration of ammonia.

$[\text{PO}_4^{3-}]$ is the concentration of phosphate.

Struvite in Waste Treatment Systems

Rawn et al. (1939) described formation of scale in pipes that followed an anaerobic sludge digester. This is one of the first reported occurrences of struvite in wastewater treatment systems. They suggested that the scale was formed due to a change in pH caused by CO_2 released when the sludge passed through pipe fittings.

Borgerding (1972) defined the problem of struvite deposits at Los Angeles' Hyperion treatment plant. In 1963 employees at the Hyperion treatment plant found the underside of separating screens coated with crystalline deposits that proved to be struvite. In 1967 the pipes that normally carried digested sludge by gravity become so heavily encrusted with scale that pumping was needed to maintain proper digester levels. The scale that formed was almost pure magnesium ammonium phosphate (struvite). The system was cleaned, but within a year the scale had again formed to the point of clogging the lines. Four factors were identified that contributed to struvite formation at the Hyperion treatment plant. The first was the relative surface area-to-volume ratio. In the digester the ratio was 0.05:1, but the ratio was 4:1 in the pipes where scale build-up was a problem. The 600 feet of 12 inch pipe had about 80 times more surface area for the scale to form than did the digester. Rough pipes, especially at joints, were listed as the second factor in the formation of struvite in the pipes. The rough pipes provided a place for struvite crystals to attach and grow. The third factor was vibrations from the sludge screens that increased the energy in the pipelines and stirred the sludge as it passed through the pipes near the screens. This stirring action was described as similar to what is done to form precipitates in a laboratory. Temporary increases in pH due to vaporization of CO_2 under reduced pressure at bends and

restrictions was the fourth factor. The rise in pH creates a more suitable environment for the formation of struvite at these points in the pipeline.

Solutions suggested by Borgerding (1972) included elimination of phosphate-rich sludge from the digester and dilution of the digested sludge to increase pipeline velocities and reduce magnesium ion concentrations. Iron pipes were also replaced with PVC pipe to reduce roughness.

Struvite in Urinary Stones

Struvite is also a major component of urinary stones of humans and some animals. The nuclei of stones are made up of less soluble compounds and struvite usually forms on the outer layers of the stones. The compounds that form the centers precipitate from urine first and may serve as seed for the formation of struvite. This allows crystallization to take place at lower supersaturation levels than normal (Abbona and Boistelle 1978).

It is thought the enzyme urease splits urea into ammonia and carbon dioxide. The increase in ammonia shifts the ammonia equilibrium, forming ammonium and hydroxides. This increases pH, which in turn shifts the phosphate concentrations to the more insoluble PO_4^{3-} forms, forming an ideal environment for struvite formation (Krawiec et al., 1984; Hedelin et al., 1985). Lagoons contain a similar chemistry and though no research has been done in this area, it is possible that this may be one pathway that struvite forms in a flush system (Westerman et al. 1985).

Recycling Flush Systems and Crystalline Salt Buildup

Booram et al. (1975) identified the problem of struvite formation in livestock waste systems. They discovered, in 1970, that scale was forming in a

pump that recycled effluent, causing the pump to fail. Two solutions were available at the time: converting to aerobic systems to oxidize ammonia or developing ways to overcome the encrustation problem. Converting to an aerobic system would require more management inputs and more mechanical parts; thus there was some concern about system failure. Anaerobic digestion requires fewer mechanical parts and is not as prone to system failure, making it the treatment of choice. Since aerobic systems are not a viable option, finding a way to control the encrustation was needed.

In their report, Booram et al. (1975) reported monitoring concentrations of ions in a test lagoon over a year and finding the following concentrations to be typical:

Mg= 48 mg/l or 1.97×10^{-3} moles/L

NH₃= 375 mg/l or 26.8×10^{-3} moles/L as N

PO₄= 250 mg/l or 2.63×10^{-3} moles/L

They found the lagoon was only mildly supersaturated and that the scale should not form as readily as it did. A possible reason for the scale forming so quickly is that the metal fittings in the pump may have provided advantageous nucleation conditions.

They found the deposition was greatest on parts made of any type of metal. Galvanized iron, black iron, cast iron, copper, bronze, and brass were all listed as having had heavy encrustation of struvite. Struvite did not form as readily on plastic parts, thus leading them to think the pipe reacted in some way to start the formation of the scale.

The experiences of Booram et al. (1975) led them to make some recommendations regarding to equipment design and maintenance. Their tests found that rigid plastic sewer and vent pipe or flexible polyethylene pipe work

better than metal pipe. Also, they recommended that pumps have plastic or rubber impellers to reduce the amount of encrustation in the pump. Since it is always likely that struvite can form, they recommend that an acid flush system be built and that a solution of acetic acid be used to clean the system. Acetic acid was chosen because it readily degrades in the lagoon under anaerobic conditions.

The problem of struvite is mainly with the equipment involved in the transport of the effluent. Safley et al. (1982) found that the scale can form quickly, clogging pipes and causing pumps to fail. Two reasons for the formation of struvite stated by Safley and others are based on the findings of Abbona et al. (1982). It was observed that struvite will not precipitate if the supersaturation ratios are less than 1.3. Safley et al. (1982) found that the ratios in a lagoon are seldom greater than 1. The ratio is the log of the ion activity product divided by the log of the solubility product constant (pIAP/pKsp). Since a lagoon is not supersaturated, nuclei must be formed or supersaturation exceeded by some other means in areas where struvite forms.

One reason for the formation of scale, where struvite ions are not above supersaturation levels, is that a foreign particle acts as a catalyst that lowers the activation energy required for nucleation. Once the nuclei are formed, growth is slow because of the low ion concentration in the solution. Large crystals are the products of this type of growth. This may explain why the scale is stretched out from the pump and into the pipes. A second possible means for scale formation is that the pump sets up shear within the liquid. This causes some particles to move faster than others hastening nuclei formation, because different size particles are bumping into one another forming more nuclei. This may explain why struvite sometimes forms in PVC pipe.

Scale Control Using Chemical Inhibitors

The control of struvite in flush-water recycling systems has to date been limited primarily to cleaning the system with acetic acid after the scale has formed, as suggested by Booram et al. (1975). However, as evidenced by experience in cleaning cooling water systems, other acids will work as well (Barker, 1981; Fulhage, 1981; Mancl and Veenhuizen 1992). Mohajit et al. (1989) reported that sulfuric acid removed struvite more cheaply and faster than acetic acid.

Experiences in the control of scale in boilers and cooling towers also suggest that the use of certain chemical compounds may serve to control the formation of struvite in flush-water recycling systems. McCoy (1983) discusses three types of chemical agents based on mode of action.

The three categories of inhibitors are:

- (1) Those that affect solubility.
- (2) Those that alter the growth mechanism of the crystals.
- (3) Dispersants, that interact with electrically charged particles.

Chemicals that effect the solubility of the scale-forming minerals are those that keep the ions of the mineral in solution even at high concentrations. In the past, chelates such as (Ethylenedinitrilo)-tetraacetic Acid (EDTA), and polymeric inorganic phosphates were used; however, newer chemicals such as polymeric organics and organic phosphorous compounds are more cost effective (Strauss and Puckorius, 1984).

Chelates tie up metal ions between two or more donor ions. In effect they grasp the metal ions and hold them (Brown and LeMay 1988). Polymeric inorganic phosphates such as sodium hexametaphosphate (Graham's salt) have been used for many years in the cooling water industry. Known by several names, polymeric inorganic phosphates are ionized polymers that can form chelate rings between any two adjacent phosphate tetrahedra. McCoy (1983) described the

mechanism by which polyphosphates control scale formation as the threshold effect. The threshold effect is the introduction of an impurity into the crystalline lattice that alters the structure and weakens the crystal, halting its formation into larger crystals.

Other scale inhibiting agents react physically with the scale-forming ions. These chemical agents are used to disperse insoluble substances, or to bring them into colloidal form. Once the scale-forming salts are in a colloidal form they can be removed from the cooling tower by continuous blowdown (Strauss and Puckorius, 1984; McCoy, 1983).

Acrylamide, a vinyl polymer, and polyethylene oxide are two synthetic polymers used to treat cooling water. These chemicals are polymeric electrolytes, which are long chain polymers containing ionic groups along the chain, and work as wetting agents or surfactants. A surfactant alters the forces that attract similar particles and between particles and metal surfaces, keeping the particles in solution as the water is being used. The use of synthetic polymers are more common than natural dispersants such as tannin and lignin sulfonates, because they are more cost effective and are more thermally and biologically stable (McCoy, 1983; Strauss and Puckorius, 1984).

Based on the experiences in controlling scale in boilers and cooling towers, Buchanan (1993) suggested an alternative to acid flushing to remove the scale: using chemical inhibitors to control or prevent struvite formation. In a bench-top study, twenty products were tested for potential use as struvite inhibitors. Of the twenty, Buchanan subjected to further study seven that showed potential. The seven products Buchanan (1993) tested in the second phase of his study varied widely in their chemical makeup and mode of action. Buchanan's evaluation

addressed the economics of a given inhibitor, as well as environmental and safety factors that would effect the final acceptance of the product by a producer.

Kelig 4000 is one of the seven products that Buchanan tested and recommended for further study. Kelig 4000 is a polymeric lignosulfinocarboxylic acid, that exhibits the threshold effect. A long chain organic chemical, Kelig 4000 is likely to be broken down biologically (McCoy, 1983; Buchanan, 1993). Kelig 4000 is approved for use in the treatment of boiler feed water in which the steam comes into contact with food. Buchanan (1993) stated that the cost of the inhibitor, if injected at 100 ppm, will be \$0.102 per 454 kilograms (1000 pounds) of liveweight per day. The relative safety and economics of this product makes it attractive as a potential inhibitor for struvite.

Mayoquest 1500 at 75 ppm completely inhibited the formation of struvite in the beaker test, and 100% of the original concentration of phosphate was still in solution after 16 hours. A linear relationship was found between concentration of phosphate in solution and concentration of Mayoquest 1500 used. Mayoquest 1500 is 60% HEDP (1-hydroxy-ethylidene-1, 1-diposphonic acid) and is thought to inhibit scale formation by chemoabsorption on the microcrystalline nuclei, thus preventing the formation of the crystal (McCoy, 1983) Buchanan noted that results of his observations substantiated the description given by McCoy (1983), and that the addition of sufficient inhibitor completely prevented the formation of crystalline nuclei. While Mayoquest 1500 prevented the formation of struvite completely, it does have some major drawbacks. HEDP is considered a corrosive material, and can cause severe burns to the skin and eyes; thus protective clothing must be worn when handling this product. Other problems may arise due to the high acidity of the material, and the high phosphate content may limit the application of the manure to land, if phosphate is the limiting factor. The cost of

Mayoquest 1500 is over ten times that of Kelig 4000, at \$1.29 per 454 kilograms (1000 pounds) of liveweight per day (Buchanan, 1993).

The third product that Buchanan (1993) tested was Cyanamer P-70. This product slowed the formation of struvite by a kinetic response. The product cost \$0.063 and \$0.104 per 454 kilograms (1000 pounds) of liveweight per day at rates of between 15 and 20 ppm, respectively. Cyanamer P-70 is approved for use in municipal wastewater treatment and is not expected to cause concern to the producer or livestock.

Buchanan (1993) reported that Ferric Chloride, at a cost between \$0.05 to \$0.15 per 454 kilograms (1000 pounds) liveweight per day, reacts almost instantly with phosphate to form insoluble complexes. This product is approved for use as a struvite inhibitor in wastewater treatment. However, a problem arises in that the insoluble ferric phosphate complexes formed may settle in pipes and pumps, causing the same problems as struvite. Ferric Chloride is corrosive and has potential to be an environmental hazard.

Millisperse 956 was evaluated by Buchanan (1993) and found to exhibit the threshold effect. At doses greater than 5 ppm it completely inhibited the formation of struvite during the mixing and settling period. At a cost of between \$0.01 and \$0.017 per 454 kilograms (1000 pounds) of liveweight per day, Millisperse 956 is the most economical of the seven products tested. However, Millisperse 956 has some risk to the producer in that it is an irritant to the skin, eyes, and nasal and respiratory passages. Some concern has been raised about the environmental impact of Millisperse 956. Millisperse 956 can revert to orthophosphate and cause some limitations in the land application of manure where phosphate is the limiting factor.

Buchanan (1993) found that Acumer 1000, at 100 ppm, exhibited complete inhibition of struvite, and at lower dosages it delayed the formation long enough to be useful in recycle systems. Acumer 1000 is not considered a hazardous material and poses no threat to the producer, livestock, or the environment. At between \$0.022 and \$0.032 per 454 kilograms (1000 pounds) liveweight per day, Acumer 1000 is very attractive as a potential inhibitor.

The final product evaluated by Buchanan (1993), Belclene 200, showed potential as a struvite inhibitor at dosages between 10 and 20 ppm. Demonstrating both the threshold effect and discrepancy inhibitory mechanisms, it delayed the formation of struvite for 16-minutes at a concentration of 10 ppm, and higher dosages inhibited the formation completely. Belclene 200 costs from \$0.029 to \$0.058 per 454 kilograms (1000 pounds) of liveweight per day. Protective clothing should be worn when mixing this product, because at full strength it is an irritant to skin, eyes, and mucous membranes (Buchanan 1993).

3. Objectives

This project was undertaken as a part of an on-going effort to find a way to control or prevent the formation of struvite scale in recycling flush systems.

Buchanan (1993) identified seven potential struvite inhibitors. The primary goal of this project was to test Kelig 4000, one of the seven inhibitors identified by Buchanan (1993), under field conditions and determine if it would prevent struvite formation.

4. Materials and Methods

The objective of this project, as stated, was to select and test an inhibitor under field conditions. The inhibitor was selected from the seven listed by Buchanan (1993). Thus, it was crucial to have a test system in which struvite would normally form so that the effects of the inhibitor could be observed. A farrow-to-finish hog operation that had reported a problem with struvite buildup in recycle system components was found. The site was evaluated and found to meet the needs of the project. With the permission of the producer, a test apparatus was set up and the testing of the inhibitor begun.

Inhibitor Selection

From Buchanan's (1993) previous work, Kelig 4000, Milspers 956, Cyanamer P-70, and Acumer 1000 are the most obvious choices based on economics and environmental hazard. In addition to economics and environmental hazard, another important criteria is the potential impact of an inhibitor on lagoon environment. Kelig 4000 is the only one of the four inhibitors that is organic in nature and has been reported to be biologically unstable. In a lagoon environment, it is necessary that the on-going processes of degradation not be interrupted. Kelig 4000 was the final choice not only because it inhibited struvite, but for its potential to biodegrade in the lagoon.

Site Selection and Evaluation

The farrow-to-finish hog operation used a recycling flush system to clean the housing units. For several years, the operation had a problem with scale forming in almost every part of the system. Based on this information, an on-site

evaluation was made of the lagoon, the flush system, and housing units. The location and accessibility of the lagoons were ideal for the needs of the project. Samples of the scale that had formed in the system were tested with X-ray diffraction, and proved to be pure struvite.

Test System Design and Testing

The formation of struvite in a flush system is dependent upon several factors, the concentration of the ions in the lagoon, pipe and pump material, type of pump used, and others. (Barker, 1981; Fulhage, 1981; Mancl and Veehuizen 1992). The system designed to test the inhibitor consisted of a three inch manifold and multiple laterals (see Figure 1). The manifold, made of schedule 40 PVC, allowed six test laterals to be supplied by one pump.

Each lateral consisted of two sections, an inhibitor-injection section and a test section. The injection portion of the lateral was made of PVC and included (from the manifold); a one inch gate valve to control flow rate, a check valve to ensure that no inhibitor injected in the lateral would contaminate another lateral, a 1" x 1"x 1/2" tee that provided the point of injection, and a sudden decrease to one-quarter inch PVC to provide a mixing point. The test part of the lateral was made of galvanized metal pipe and started with a section of one-half inch pipe. As shown in Figure 1 the lateral then turned 90 degrees and abruptly reduced to one-quarter inch pipe, followed by another 90 degree change in direction. This section was fitted with two unions and served as a test section for monitoring struvite formation. After the test section, the lateral returned to its original size and terminated in a straight section of pipe. Flow rates through each lateral were initially set at two gallons per minute, but declined as blockage developed. A pressure gage attached at the manifold was useful in monitoring system

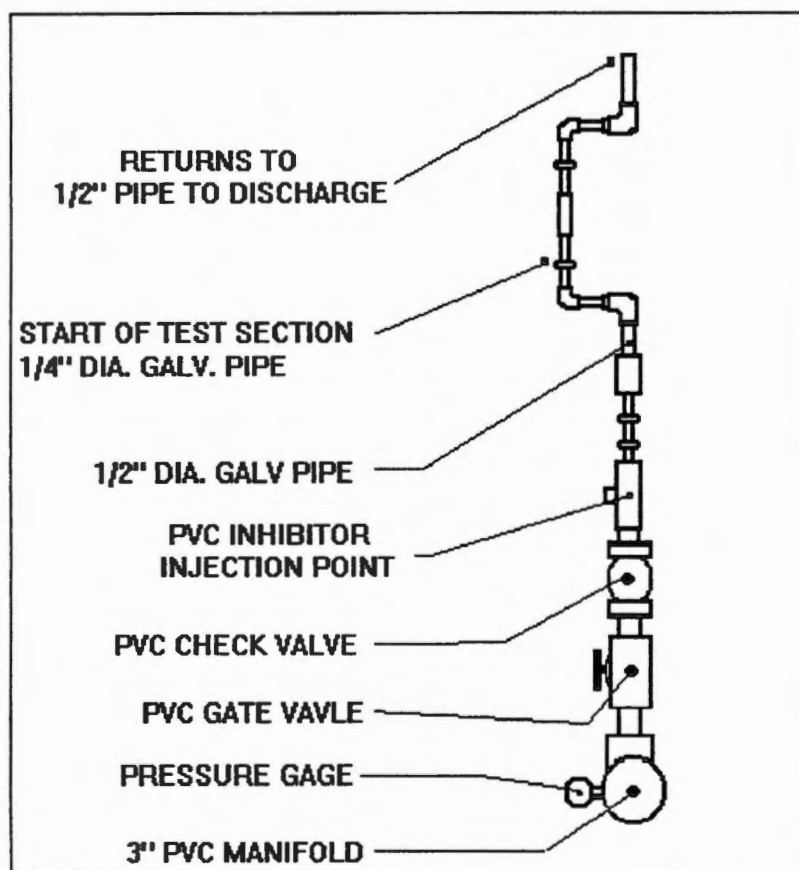


Figure 1: Test Apparatus.

performance. A drop in flow rate accompanied by an increase in pressure indicated the development of a flow restriction.

Inhibitor was injected into each lateral by a positive displacement metering pump (one pump per lateral). The flow rate of each pump was determined and a dilution factor was calculated for the inhibitor to insure the desired quantity of active ingredient was added.

To determine if struvite would in fact form in a control section of the test apparatus (i.e., no inhibitor injection), a small version, consisting of three laterals, was initially constructed and placed into service. After 14 days of continuous operation, all three lines were severely encrusted with scale.

Test Protocol

The experiment consisted of two treatments replicated 3 times along the manifold. The first treatment was the injection of Kelig 4000 at 100 ppm. The second treatment was the injection of water at the same rate of injection. The second treatment served as a control. The test period was two months, and the weight of each lateral was recorded weekly.

The inhibitor, Kelig 4000, was obtained in 55 gallon drums of 45% active ingredient. The rates at which the metering pumps operated required that the inhibitor be diluted. Thirty-two gallon capacity heavy-duty plastic garbage cans served as reservoirs for the mixed inhibitor. A calibration curve of depth versus volume was developed for each can. The equation for the calibration curve was used in conjunction with measured depth to find the volume of inhibitor injected. The initial depth of each can was recorded and the volume calculated. The required amount of inhibitor was then added to the tank. The system ran for

twenty-four hours, after which the final depth was measured and the volume injected determined. The tanks were then refilled and the process repeated.

The test system was setup and allowed to run for two weeks while final calibrations and adjustments were made. During this two-week period, water was injected into all six laterals. At the start of the third week, inhibitor was added to the first, third, and fifth lateral. At the end of each week, a section of each of the six laterals was removed and weighed.

X-Ray Diffraction of Scale

Several times during the study, samples of the scale that formed were collected and analyzed using a Siemens Kristalloflex model DACO-MP X-ray diffraction unit. X-ray diffraction is a means of identifying crystals by measuring the angles at which a given crystal reflects an X-ray (Quinn, 1970). Each crystal reflects X-rays in a different pattern, and when compared to the output of a known sample the unknown can be identified.

Samples, collected for X-ray diffraction, were scraped from the surface on which they had formed and were placed in labeled, air tight zip-lock bags to preserve them until they could be analyzed.

Statistical Analysis of Results

SAS (Schlotzhauer and Littell, 1987) was used to analyze the results of the inhibitor test. The change in weights of the test treatment was compared with the weight changes of the control treatment using the ANOVA procedure.

5. Results and Discussion

Preliminary Results: from Site Evaluation and System Testing

There were three aspects of the site that were critical to the success of the project. The first was the potential of the lagoon effluent to form struvite. The second was the location of the site and its accessibility for daily monitoring of the tests, and the third was the availability of electrical power and a fresh water source. An inspection of the farrow-to-finish operation mentioned earlier found that the last two requirements were easily met. The first required an inspection of the recycling flush system in use at the farm and an x-ray diffraction analysis of the material found at the site. Figure 2 is the x-ray diffraction output for the scale collected at the site and shows that the scale is pure struvite.

Once it was determined that the lagoon had the potential to form struvite, the test apparatus was set up. After fourteen days of continuous running the pipe was almost completely blocked with struvite. Figure 3 shows the clogged section of pipe from which a sample of scale was collected for X-ray diffraction analysis. Figure 4 is the output for the x-ray diffraction of the scale that formed in the test system during the preliminary system test. The graph shows that the scale is almost pure struvite.

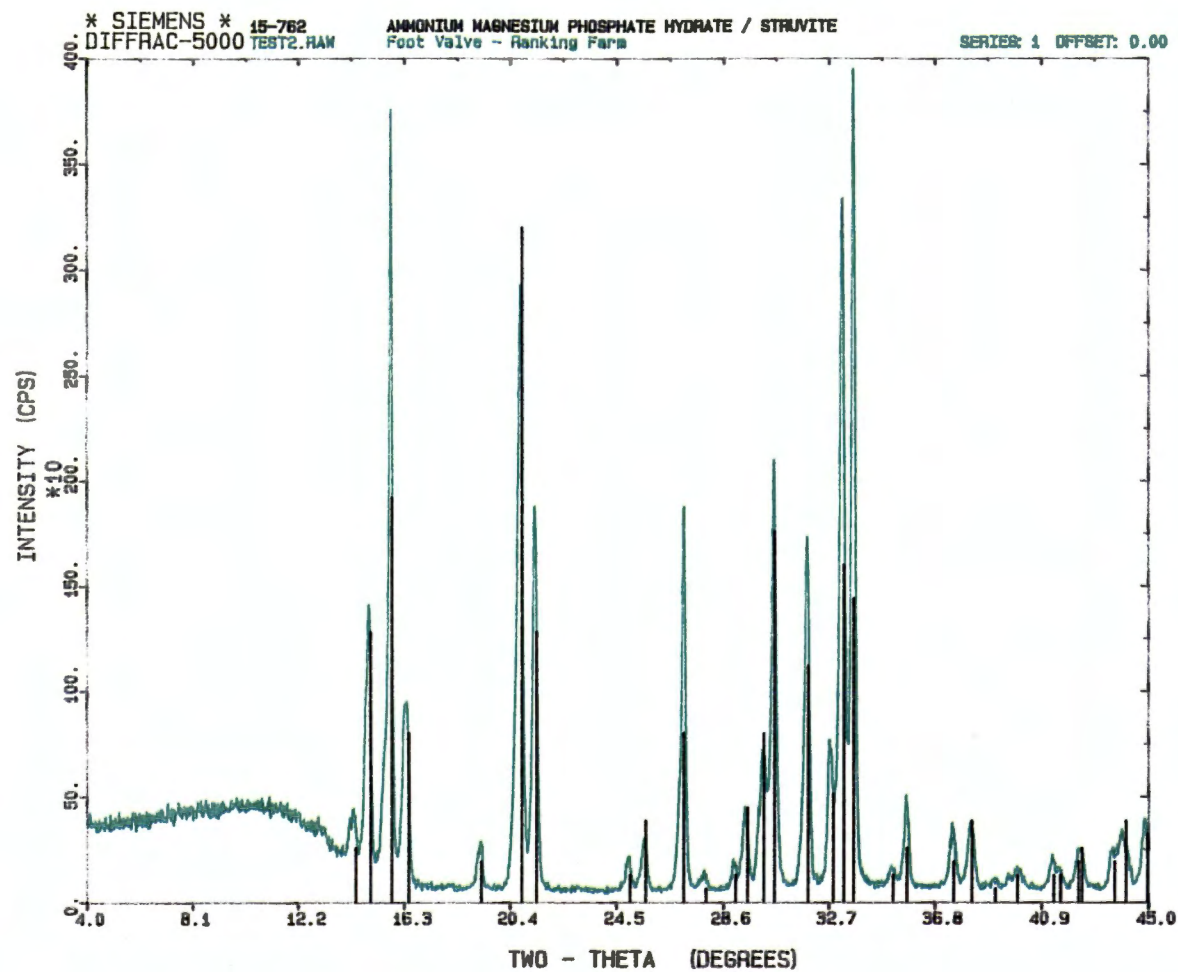


Figure 2. X-ray Diffraction Results of Sample From Rankin Farm. The vertical dark lines indicate the known sample, and the continuous light line the unknown sample. Where the continuous line matches the vertical lines indicates the two samples match if all points match then the unknown is the same as the known.

Figure 3. Test Section of Pipe the flow through which has been restricted with Struvite.



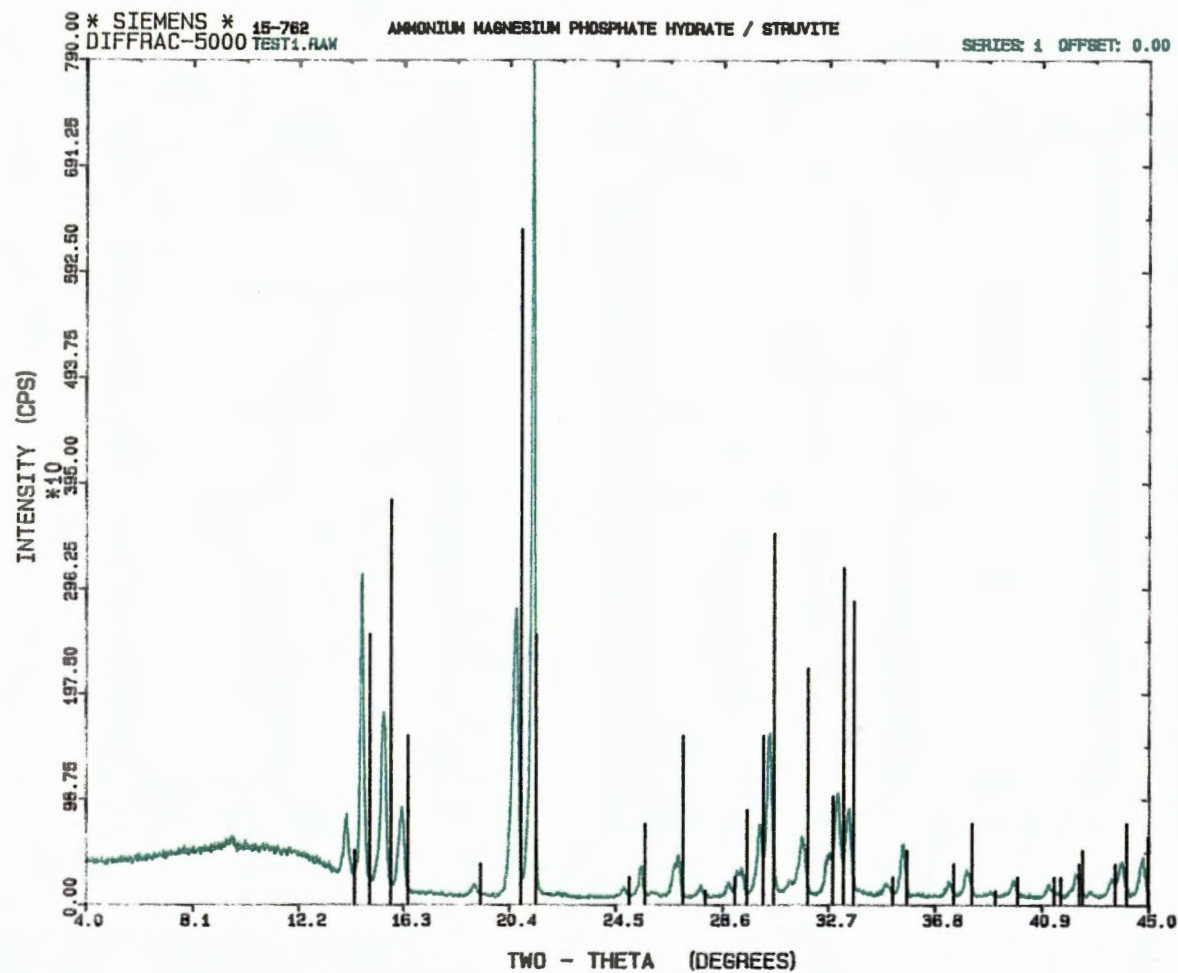


Figure 4. X-ray Diffraction Results of Scale Sample From Test Apparatus. The vertical dark lines indicate the known sample, and the continuous light line the unknown sample. Where the continues line matches the vertical lines indicates the two samples match if all points match then the unknown is the same as the known.

Inhibitor Test Results

The results of the inhibitor test are shown in Table 1 and indicate that there is an effect of the inhibitor. The weight gain numbers were found by subtracting the weight of the test sections at the start of inhibitor injection from the final weight of the test section at the end of the test. The laterals that were injected with the inhibitor (laterals 1, 3, and 5) showed a net loss in weight, suggesting that Kelig 4000 removed struvite that had formed during the two-week calibration period. The control laterals continued to increase in weight throughout the test period.

An analysis of variance (ANOVA) was performed on the data using SAS. The ANOVA procedure produced the results that are shown in Table 2. A coefficient of determination of 0.9098 indicates that the statistical model explained 90.98% of the variability in the data. The case is very strong that the inhibitor prevented scale formation. In fact, there is only a 0.03% probability that the difference observed could have occurred by chance.

Table 1 Results of Inhibitor test.

TREATMENT	INITIAL WEIGHT (grams)	FINAL WEIGHT (grams)	WEIGHT CHANGE (grams)
TEST	367.95	366.87	-1.08
TEST	331.91	331.5	-0.41
TEST	339.20	338.32	-0.88
TEST MEAN			-0.79*
CONTROL	374.14	375.22	1.08
CONTROL	330.64	331.56	0.92
CONTROL	295.00	295.53	0.53
CONTROL MEAN			0.84*

* means are significantly different at the 99.7% level of confidence.

Table 2 Analysis of Variance using SAS ANOVA Procedure.

Analysis of Variance Procedure

Dependent Variable: GAIN

Source	DF	Sum of Squares	F Value	Pr > F
Mode	1	4.00166667	40.35	0.0031
Error	4	0.39666667		
Corrected Total	5	4.39833333		

R-Square	C.V.	GAIN Mean
0.909814	1180.903	0.02666667

Source	DF	ANOVA SS	F Value	Pr > F
TRTMNT	1	4.00166667	40.35	0.0031

6. Conclusion and Recommendations

Conclusion

The results of this research project indicate that Kelig 4000 will inhibit the formation of struvite in recycling flush systems. The statistical analysis of the data suggest that 90.98% of the variation between treatments was due to the Kelig 4000 inhibitor, and that this variation is significant.

Recommendations for Future Research

The results of this test were for Kelig 4000 injected at 100 ppm; it is possible that the inhibitor will work at lower dosages or be more economical if used at lower rates. Also, Kelig 4000 is not the only potential inhibitor that has been identified. Other potential inhibitors need to be examined under field conditions and their results compared with the results produced by Kelig 4000 before final recommendations are made.

The problem is not as simple as finding an acceptable inhibitor. Struvite can cause problems in the entire recycling flush system, thus the inhibitor must work through the entire system. The farrow-to-finish hog operation at which this research project was conducted is an excellent example. Struvite formations could be found in the foot valve on the pump intake line, the pump itself, the flush water delivery piping, as well as on all surfaces of the tipping buckets. Thus, the inhibitor must be injected at the pump intake and maintain its potency until the recycled water is returned to the lagoon. Thus, there is a need to design an injection system that is simple to operate and will inject the inhibitor at the start of the recycling system.

Another area that must be considered is economics. While Buchanan (1993) addressed the cost of the inhibitors he tested, he did not compare their cost to other alternatives such as acid flushing. Therefore, a thorough economic analysis of the cost of controlling struvite with an inhibitor versus the cost of alternative methods is needed.

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