MODIFICATIONS TO A PRAYON REACTION SYSTEM TO INCREASE CAPACITY AND CIRCULATION.

Joseph R. Schneider

Farmland Hydro L. P.

INTRODUCTION

This paper will discuss the changes made to the Phosphoric Acid Department Southside reactor at Farmland Hydro, L.P. during the time period of March 1992 to the present. Discussed will be the modifications made to the internals of the digester, changes made in agitators, circulating pumps and the addition of a larger flash cooler. The changes to the reactor are still be done to this day to alleviate the hydraulic limitations associated with this type of reaction system. The present circulation rate is at its maximum without making the digester one large stirred tank. Also discussed in this paper will be the rationale of why certain modifications were made, others that were considered and pitfalls that were encountered on our way to where we are today.

HISTORY

Farmland Hydro, L.P. , originally Consumers Cooperative Association built the Phosphoric Acid Department #1 (PAD 1) south digester in 1965. The digester was a PRAYON type unit designed by Gulf Design. The original design capacity of the reaction system was 325 tons per day P_2O_5. The reaction system was composed of a nine (9) compartment digester with dry rock, diluted sulfuric acid, and recycle acid being added to either of the first two (2) compartments. The first two compartments had 3,013 and 2,375 cubic feet of volume respectively, with compartment #1 under flowing to compartment #2. The reactor slurry then overflowed from #2 to #3, underflowed from #3 to #4, and so on through out the system until it came to #8 compartment (see Table 1 detailing compartment volumes) where it entered any one of three (3) circulating pump well compartments fitted with three Hazelton VNB pumps that provided approximately 2,900 gallons per minute circulation. The discharge of the circulating pumps was to a 10' diameter by 10' tall flash cooler where it was injected to the bottom, in a fountain fashion, and overflowed to the seal box in the #9 compartment. The original Bird 24 B filter was fed at 444 GPM and had a three (3) wash system. The flash cooler was later changed to have two (2) inlets installed tangential to the side and drain from the cone bottom to the #9 compartment seal box. The original down leg to the seal box was 36" diameter. Additional cooling was provided by the dilution coolers that cooled the sulfuric acid as it was diluted from 93% strength to approximately 55%. The dilution coolers removed $10.36x10^6$ BTU/HR while the slurry cooler removed $14.76x10^6$ BTU/HR with a delta T of 6 degrees Fahrenheit In 1981 a Bird 24 D filter was installed on the south side reaction train, replacing the 24 B filter. The larger filter would not be fully utilized until 1992 with addition of greater cooling capacity.

In 1991 the complex was converted from dry rock grinding to wet rock grinding. The effect of the conversion was that the sulfuric would no longer be diluted and the dilution coolers would have to be removed from service. The heat that had been removed via the coolers was now loaded on the flash cooler. The temperature in the reactor was no longer run at the original design of 164 °F and 6 degrees delta but was raised to 194 °F with a delta T of 12 degrees. No modifications had been made to increase circulation from the original design in an attempt to lower the operating temperature and delta T. The addition of a larger flash cooler was required to bring the temperature down and to be able to fully utilize the filter that had been installed earlier.

MODIFICATIONS DONE IN MARCH 1992 TO FEBRUARY 1996

The new flash cooler was designed by Raytheon Engineers and Constructors in January of 1991. The original design called for the direction of circulation to remain according to the original design of counter clockwise as viewed from overhead. The suction for the new flash cooler circulating pump would have been a 36" diameter Jessop 700 nozzle inserted on the east side of the digester from the #8 compartment located next to the filtrate tanks, inside the building. The problem with locating the pump indoors caused a great amount of concern for two reasons. The first reason of concern was the ability to maintain the pump indoors since it would be nearly impossible to bring a crane that could lift the parts of the new pump and still clear the ceiling height. The second reason of concern was the discharge line from the circulating pump would have to cross over the top of the digester, thereby eliminating the ability to utilize the bridge crane for removal of the agitators in compartments 9, 1 and 2. A future concern was that there was not enough room inside the building on the east side of the digester to set a second pump if an increase in circulation was desired. Mr. Bob Fox, Maintenance Manager, and I discussed the possibility of setting the pump on the west side of the digester and reversing the direction of circulation, to a clockwise direction as viewed from overhead. In October 1991 it was determined to make the change in circulation direction, which offered many favorable items. The most beneficial item was the placement of the circulating pump outdoors that allowed the pump to be available for ease of maintenance. Another item of benefit was that the length of run for the discharge from the circulating pump was cut down by the distance over the digester. A side benefit was the sulfuric acid line which had been previously run across the top of the digester only had to come to the east side for its new tie in location at compartments 7 and 8. The compartment numbers were kept the same for ease of transition with the operators and for the existing mechanical, instrumentation and electrical labeling and files. The recirculation from the #2 filtrate tank was conveniently tied into the #7 and #8 compartments which are located just adjacent to the filtrate tanks. We were also fortunate that some time in the past a 36" diameter opening had been cut into compartment #1 for the purposes of cleaning, this opening would become the suction nozzle for the new circulating pump. The down side to the reversal of the circulation was that the internal walls of the digester would have to be modified to allow for the reversal of flow as well as the overflow and underflows would have to be checked to see if they could handle the expected increase in flow rate. Several people contributed to the changes that would have to be made to both the digester flash cooler and piping. Case Engineering was contracted to do the modifications to the piping and structural steel, while R. T. Schneider P.E. was contracted to calculate the new hydraulic conditions inside the reactor.

REACTOR MODIFICATIONS

Modifications to the internals of the reactor included sealing the overflow weir from the existing down leg seal box to compartment #1. This change was the primary one necessary to reverse the digester flow. Previously the flow from the flash cooler would enter the seal box area and flow into compartment #9 as needed for feed to the filter. The remaining liquid would return to compartment #1 to circulate again. The design effect was to have compartment #9 as a retention area prior to feed to the filter. The #9 compartment with a volume of 18,100 gallons would allow for a retention time of forty (40) minutes, based on design operating rates. With the change in direction of circulation there was no longer a compartment for retention prior to feed to the filter. One of our main concerns was the effect this would have on the losses from the gypsum cake, primarily the citrate soluble losses. We feared that the increase in circulation would be offset by the loss of the retention time in compartment #9. As can be seen by the CHART #1, the citrate soluble losses did not change drastically. The general consensus is to have a fair amount of retention time prior to feeding the filter, however due to our low circulation rate the reaction has probably gone to completion prior to completing the circuit around the digester and does not impact the losses from a retention standpoint. A higher circulation rate may require a set period of retention time to minimize losses, but circulation rates as high as would be needed to see the effect would not be possible within the existing reaction architecture (see conclusions listed below for the calculated maximum flow rate). Prayon recommends a 2:1 ratio of reaction section to digestion section. Our current layout has no digestion section at all.

The seal leg penetration in the seal box was enlarged to handle a 48" HDPE down leg tail piece. HDPE down legs are preferred in our complex for their ease of cleaning, and their corrosion resistance. The one drawback to HDPE is of course the wall thickness required for strength, at temperature and vacuum conditions. The HDPE down leg tail piece was later changed to a 60" OD piece made from 317L stainless steel material. The reason for the change was to alleviate the hold up of liquid in the down leg that was causing scaling in the discharge of the flash cooler. The opening in the roof of the digester had to be enlarged to accommodate the larger diameter tail piece and, internally, the seal leg compartment had to be enlarged. The opening up of the seal leg compartment involved the removal of the wall between the compartment and the old original filter feed pump compartment. In addition to the removal of the wall between the seal well and the pump well was the removal of the arch and wall between the #9 compartment and the pump well seal well combination. Removal of all these walls is possible since the roof of the digester is essentially spanned from the outside walls to the wall running down the center of the digester in a north / south orientation.

Overflow weirs were cut between compartment #9 and the circulating pump wells in #8 to allow for the reversal of flow, the archways between the circulating pump wells and compartment #8 were cut to prevent the wells from building up with solids and restricting flow. The overflow weirs were cut to be 4'-9" wide by 3'-0" high when finished with brick. It was calculated that the liquid level flowing over these weirs would be one foot in depth with one foot of foam on top allowing for one foot of clearance between the top of the foam and the underside of the roof.

CIRCULATING PUMP

The initial pump was a Warman slurry pump (550 TUL) that was rated at 18,000 GPM at our conditions. The original impeller was of Sanicro 28 material which gave us good life, both from a corrosion and erosion standpoint. The Sanicro impeller was available at the time of our project and was not the original design, it did however give us 23 months of service . The Sanicro impeller was replaced with a rubber covered impeller which gave us four months of service, followed by another which lasted but one month. The rubber covered impeller was replaced one additional time, which lasted four months. This impeller was replaced with one of A-500 material. However a defect in the casting caused the impeller to crack after one day of operation. The replacement for the A-500 impeller was the rebuilt Sanicro 28 which was used for 6 months and replaced with an impeller of Cd4 material, which has lasted 11 months to the present.

The one problem with the layout of the suction piping for the circulating pump is the rubberlined reducing eccentric lateral that feeds the original pump. The lateral has a tendency to wear at the inside angle edge of the reducing leg. Abrasion resistant coatings have been tried on the edge as well as various rubber compounds as it was patched. The ultimate fix will be to replace the lateral with one of all alloy construction of either Hastelloy G30 or 904L stainless steel.

A second Warman 550 TUL slurry pump was installed in August of 1995. The second pump was proposed in three different scenarios. The first was to have the suction come from compartment #3 which was fitted with a 36" manway, similar to the one in compartment #1, and discharge to compartment #8 to increase circulation; however, flow would bypass the flash cooler. This idea was rejected for the fact that the flash cooler could handle the additional flow rate and we wished to have as low a delta T as possible. The second option was to tie the two pumps together with common suctions and common discharge. Representatives from Warman recommended against this because the pumps could work against one another, or circulate internally. In one similar application the pumps were not started in unison and broke the shaft on one pump due to the increased load from the operating pump. The third option was to have a common suction but with separate discharges. This option both protected the pumps and allowed for the full circulation through the flash cooler and is the option chosen. The one draw back has been that the increased pressure drop through the suction piping has limited the range of level in the digester and has not allowed us to see the full circulation rate from both pumps. One other limitation, that has not been resolved as of yet, is that the nozzles entering the flash cooler are only 24" ID and greatly restrict the flow to the cooler. The plan for replacing the nozzles is to go to a modified nozzle that would have the effective radius of 30". The nozzle change will be made later in 1996.

AGITATORS

In 1984 the tops of compartments 1 and 2 were opened up to allow for larger diameter agitators to be installed in a effort to gain better mixing in the zone where the rock and sulfuric were being added. The agitators installed were Lightning A310 foil type agitators. The design was supposed to more efficiently utilize the 100 hp input to the reaction volume.

The only disadvantage was that the foil type blade was of a narrow design that did little for the entrained gas that is formed. When the digester direction of circulation was changed the agitators that had been in compartments 1 and 2 were moved to compartments 7 and 8. The roofs of compartments 7 and 8 had to be opened to 5'-6" square opening to allow for the agitator installation. The agitators, though not the ideal selections for the compartments where the rock, sulfuric, recirculated acid, and recycle acid from the filter enter together, did provide increased agitation in the compartments as compared to the original flat blade impellers.

The Lightnin A-310 agitators were replaced in compartments 7 and 8 in February 1995 with Lightnin model A-320 turbine bladed agitators. The A-310 agitators were returned to compartments 1 and 2 at this time. The new A-320 agitator were designed to fit in the existing openings on compartments 7 and 8 as well as require no more horsepower than the existing gear boxes would handle. The gear boxes were recent purchases after a long campaign to replace the original gear boxes for all the agitators for the digester. The result was an agitator that fully utilized a 150 horsepower motor and would provide the best agitation thus far, since they are designed to pump in a 20% entrained gas liquid. The blades are much broader faced than any other blade on agitators in this digester and do provide greater mixing in these compartments. The one drawback to the original design of the A-320 impellers was the installation of stabilizing fins on the bottom set of blades on the agitator in compartment #7. The stabilizing fins presented a flat surface, as they rotated, that was in the area of flow from the underflow between compartments 7 and 8. The calculated velocity, with both pumps running, was 3.25 ft/sec which caused flexing of the agitator shaft. The ultimate result of the flexing was to cause the shaft to shear off at the point where it tapered down to fit into the coupling half for attachment to the gear box. The stabilizing fins have been removed and we have not had any further shaft breakage due to this problem.

FILTER FEED PUMP

When the modifications were made in March of 1992 the original 6" Nagle vertical filter feed pump was kept in place. The pump was driven by a 75 horsepower motor operating at 1750 RPM with a variable frequency drive providing the control. The pump was found to provide only 1,300 GPM at optimum conditions and would not allow us to reach our full filter potential. Arroyo Process Equipment supplied us with a 8X6 Warman slurry pump with all A51 liner material and impeller. The motor is a 100 horsepower 1750 RPM with variable frequency drive. The pump was installed to the north of the #9 compartment on an existing bottom suction nozzle. The Warman horizontal pump delivered in excess of 1,500 GPM. The down side to the position of the suction location was that it had a tendency to suck the lumps off the bottom of the compartment and restrict flow. The pump suction was changed to a nozzle that was located approximately four feet above the bottom suction which all but eliminated the pluggage problem. One negative to the use of the horizontal pump has been the dilution caused by the use of seal water. With a properly maintained seal and or packing we have been able to reduce the dilution effect to a minimal level. The wear material of A51 has given us wear life in excess of one year.

RELOCATION OF FUME DUCT

The original fume duct was tied into the roof of compartment #6. The change in direction of circulation caused the fume take off point to be in one of the compartments with the possibility of large amounts of foam. This duct was relocated to one of the western most manways located over the wall separating compartments #3 and #4. The wall between these two compartments was an underflow, and it was felt that it was an ideal location for the location of the fume removal duct due to it being far enough away from the compartments of foam generation. The duct was installed by Lane Piping and Equipment and is 36" HDPE. The routing for the fume duct is external to the building and ties into the original fume scrubber. The fume scrubber has passed all environmental compliance tests since the change in circulation direction and increase in rate. Manways were installed in each of the elbows of the fume duct system to facilitate cleaning. The fume duct has been cleaned approximately four times since its installation. Ideas for preventing the build up of material in the duct have included putting a greater slope on the duct and spraying process water into the air stream.

MODIFICATIONS DONE IN FEBRUARY 1996

REACTOR MODIFICATIONS

Three changes were made to the digester in February of 1996. (1) Lowered the weir height between compartments 9 and 8, (2) installed a 6' x 4' manway on compartment 8 and (3) slotted the wall between compartments 7 and 8 (see sketch). Lowering of the weir between 9 and 8 was done to allow the foam that was being held up in compartment 9 to travel through the circuit. The weirs were lowered an additional 3 feet to match the weir height between compartments 6 and 7. Lowering of the weir required that the down leg from the flash cooler into compartment #9 be lowered to maintain the vacuum seal. The leg had to be tapered from the original 60" OD to 54" OD to allow for the taper associated with the battered walls in the digester. The 6' x 4' manway was installed on compartment #8 to shorten the cleaning time of this large compartment and compartment #7. The addition of rock into either one of these two compartments causes them to be build up greater than any other compartment in the circuit. It is felt that we will be able to use the large manway in conjunction with the slot cut between #7 and #8 to high pressure water blast the compartments and clean from overhead without endangering any personnel due to the extensive overhanging buildup that is frequently found in these compartments. The slot cut between compartments 7 and 8 is approximately 6'-8" wide by 10'-4" tall. The slot was cut to lower the level in the reactor on the front end to overcome the head requirements in compartment #1 for feed to the circulating pumps.

CONCLUSIONS

1. Compartment #9 being a flow through compartment rather than its original design of a retention compartment has not shown to have a negative effect as we thought it would due to the increased circulation rate throughout the digester.

2. The changes have allowed us to increase circulation rates from the original 5,800 GPM to a calculated rate of 27,000 GPM, without having foam over spilling the digester compartments.

3. Horizontal pumps in filter feed service can be a source of dilution, but with proper maintenance of seals the dilution can be eliminated.

4. The production capacity of the reaction system has been increased to over three times its original design without affecting the losses when compared with the production rate.

5. The changes thus far have shown that on the front half of the digester it is the overflow weir between compartments 6 and 7 that controls the liquid level.

6. The controlling element on the backside of the digester is the underflow between compartments 3 and 4, due to the high pressure drop.

7. The present configuration of the digester would allow us to increase the circulation to a maximum of 30,800 GPM, which would cause the pumps suction piping to lose 3.28 ft of head and the over flows and under flows lose 3.58 ft of head. The maximum flowrate is based on allowing the liquid level to be 1 foot from the underside of the roof in compartment #9.

8. The maximum flow rate possible if slots were cut in the walls between compartments 1 &2 and compartments 3&4 would be 34,100 GPM with pump suction losses of 4.14 ft and 2.57 ft loss with the one remaining underflow and overflows. Again the maximum is based on allowing 1 foot of clearance between liquid and ceiling.

9. A completely modified reactor would have only the center wall with baffles as remnants of the overflows and underflows. The center wall would remain to support the span of the roof. Overflow weirs would be kept between compartments 8 and 9 to prevent back mixing and Circulation would be limited by the suction piping losses and the capacity of the pump(s). Based on our present piping arrangement we could realize a circulation rate of 36,300 GPM with 4.78 foot of head loss in the suction piping, assuming the pumps could deliver this volume.

TABLE 1

(Year 1965)

Compartment	volume ,ft³	agitator blades/dia	horsepower
1	3,013	flat / 48"	100
2	2,375	flat / 48"	100
3	3,013	flat / 48"	100
4	2,375	flat / 48"	100
5	3,438	flat / 48"	100
6	3,762	flat / 48"	100
7	5,446	flat / 48"	100
8	5,643	flat / 48"	100
circulating pump wells(3)	522	N/A	N/A
9	2,420	flat / 48"	100
filter feed pump well	538	N/A	100
Total	33,589		900

(Year 1984)

Compartment	volume ,ft³	agitator blades/dia	horsepower
1	3,013	foil/ 78"	100
2	2,375	foil / 78"	100
3	3,013	flat / 48"	100
4	2,375	flat / 48"	100
5	3,438	flat / 48"	100
6	3,762	flat / 48"	100
7	5,446	flat / 48"	100
8	5,643	flat / 48"	100
circulating pump wells(3)	522	N/A	N/A
9	2,420	flat / 48"	100
filter feed pump well	538	N/A	100
Total	33,589		900

(Year 1991)

CHANGE TO WET ROCK

Compartment	volume ,ft^3	agitator blades/dia	horsepower
1	3,013	foil / 78"	100
2	2,375	foil / 78"	100
3	3,013	flat / 48"	100
4	2,375	flat / 48"	100
5	3,438	flat / 48"	100
6	3,762	flat / 48"	100
7	5,446	flat / 48"	100
8	5,643	flat / 48"	100
circulating pump wells(3)	522	N/A	N/A
9	2,420	flat / 48"	100
filter feed pump well	538	N/A	100
Total	33,589		900

(Year 1992)

FLASH COOLER INSTALLED

REVERSED DIRECTION OF CIRCULATION

Compartment	volume ,ft^3	agitator blades/dia	horsepower
1	3,013	flat / 48"	100
2	2,375	flat / 48"	100
3	3,013	flat / 48"	100
4	2,375	flat / 48"	100
5	3,438	flat / 48"	100
6	3,762	flat / 48"	100
7	5,446	foil / 78"	100
8	5,643	foil / 78"	100
circulating pump wells(3)	522	N/A	N/A
9	2,420	flat / 48"	100
filter feed pump well	538	N/A	100
Total	33,589		900

(Year 1996)

REMOVE WALL BETWEEN COMPARTMENTS 7 & 8

Compartment	volume ,ft^3	agitator blades/dia	horsepower
1	3,013	A310 foil / 78"	100
2	2,375	A310 foil / 78"	100
3	3,013	flat / 48"	100
4	2,375	flat / 48"	100
5	3,438	flat / 48"	100
6	3,762	flat / 48"	100
7	5,446	A320 / 71"	150
8	5,643	A320 / 71"	150
circulating pump wells(3)	522	N/A	N/A
9	2,420	flat / 48"	100
filter feed pump well	538	N/A	100
Total	33,589		1,000

CHART 1

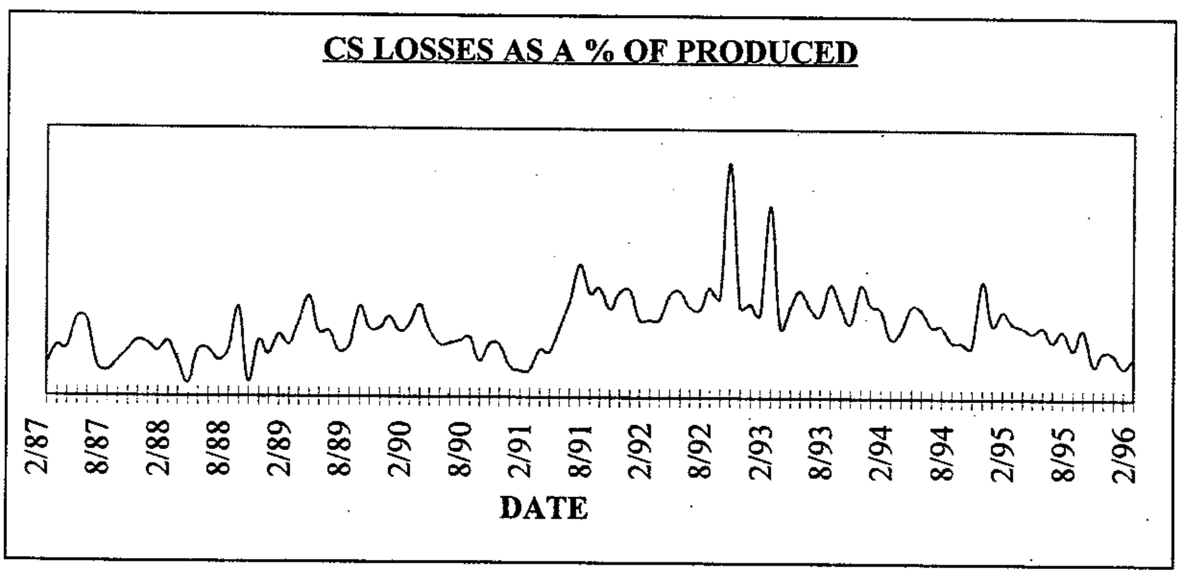


CHART 2

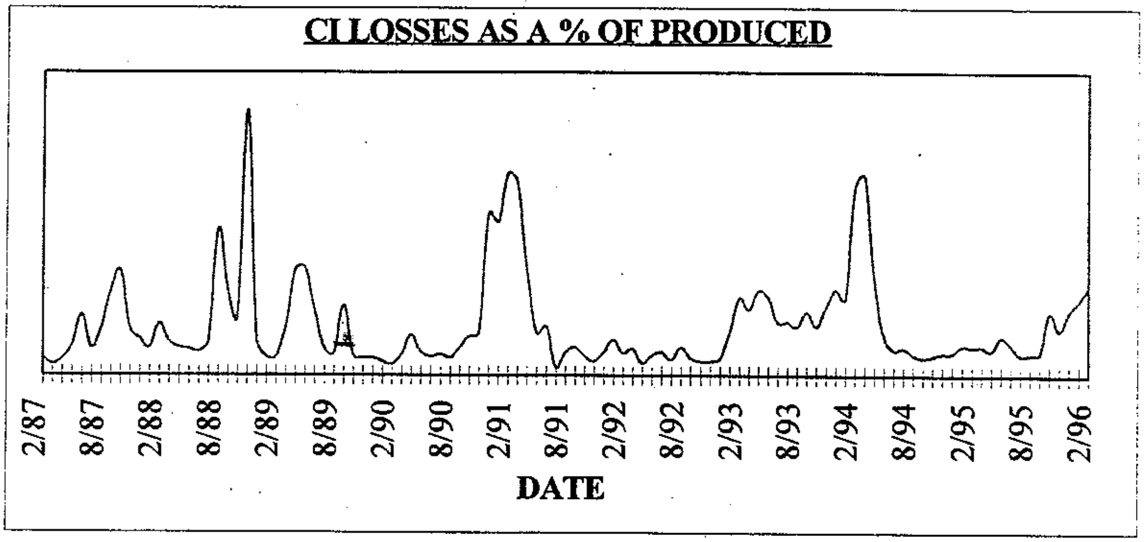
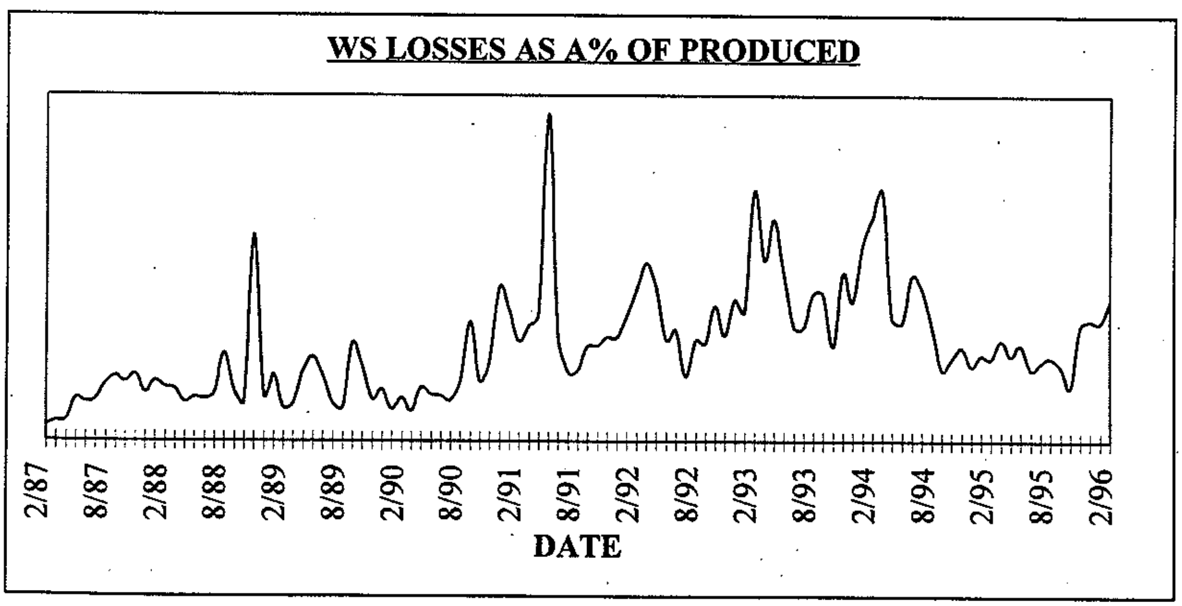


CHART 3



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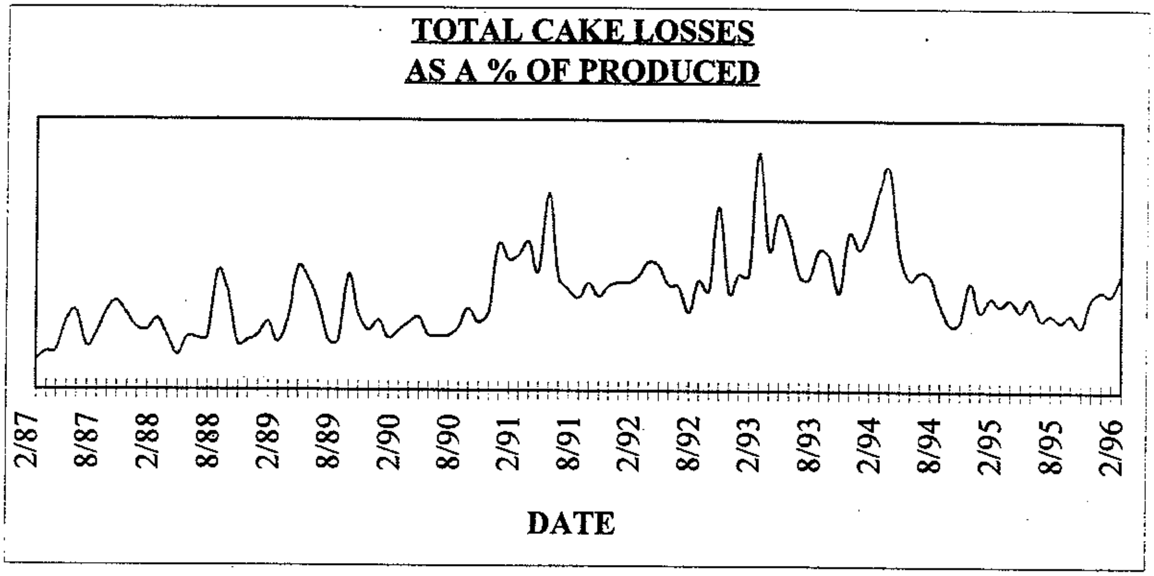
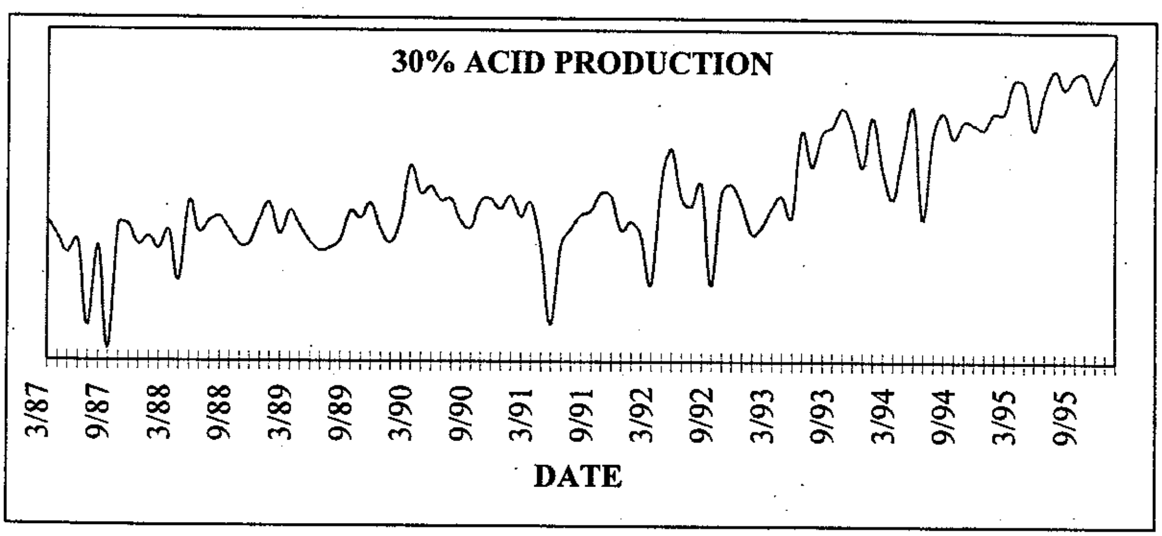
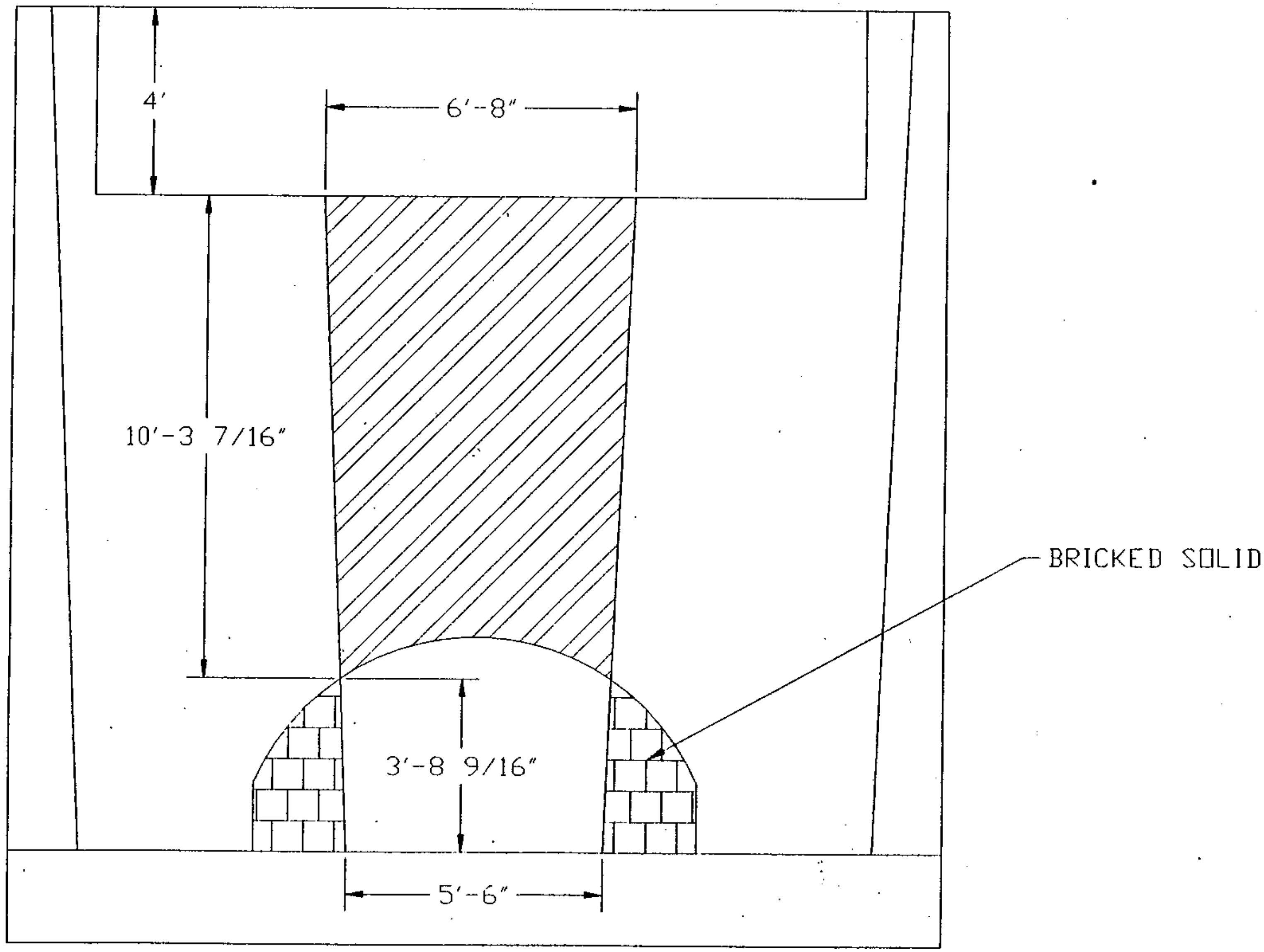


CHART 5





SLOT CUT BETWEEN
COMPARTMENTS 7 AND 8