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PROGRAM FOR ENSURING HB-LINE DISSOLVER DILUTION FLOWS WHEN PROCESSING HIGH HYDROGEN MATERIAL (U)

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1.0 Summary

When dissolving oxides, the only significant hydrogen production mechanism was from radiolysis of the solution. Hydrogen concentration control was accomplished by purging process air through the solution. When dissolving solid scrap, hydrogen may be produced chemically during dissolution at a rate much greater (usually ≥ 1000 times) than radiolytic hydrogen, and purge is achieved by drawing glovebox air through the dissolver charge chute using the vessel vent system.

Material that chemically generates hydrogen in nitric acid, such that the hydrogen concentration in the chemically-generated gases does not reach the Lower Flammability Limit (LFL) if all dilution flow is lost, is known as "non-high hydrogen" material. The beryllium port into the charge chute is plugged and the dissolver is operated with the charge chute cover on. A hole in the charge chute allows air passage to dilute the chemically-generated hydrogen. A vacuum gage ensures sufficient air is being drawn into the dissolver to maintain the hydrogen concentration in the dissolver vapor space at ≤ 25% of LFL.

Material that chemically generates hydrogen in nitric acid, such that the hydrogen concentration in the chemically-generated gases would reach or exceed LFL if all dilution flow is lost, is known as "high hydrogen" material. When dissolving "high hydrogen" material, the dissolver charge chute cover is made inaccessible. There is a very low vacuum in the dissolver because the resistance of the charge chute to flow is significantly less than other components in the flow path, such as the condenser. It is impractical to measure dilution flow in the dissolver by measuring vacuum in the vessel ventilation system pipe between the dissolver and the condenser. The dilution flow available with the charge chute cover off was measured before processing was initiated, and a conservative interpretation of the results was made to establish the amount of dilution flow credited in this mode.

This document describes the program used to ensure that airflow is maintained in the vessel vent system while dissolving high hydrogen material. This is to comply with the requirements for evaluating potential dilution flow degradation as required in TSR 6.4.17.1.

2.0 Introduction

When dissolving solid scrap, chemical hydrogen may be generated because of metals or other materials that can undergo oxidation-reduction reactions with nitric acid. If the concentration of hydrogen in the chemically-generated gases is such that the concentration in the dissolver vapor space will exceed the Lower Flammability Limit (LFL) in air if all dilution flow is lost, the material is designated as "high hydrogen" material.

The discussion in this paragraph is for dissolving "high hydrogen" material. Dilution flow for controlling hydrogen to less than or equal to 25% of LFL, for normal processing, is from suction through the dissolver with the vessel ventilation system. The motive source for this system is the Phase I glovebox exhaust fans. For off-normal processing conditions, the motive force is the H-Canyon Exhaust fans, and hydrogen is controlled to less than LFL for off-normal conditions. To get maximum flow from the H-Canyon exhaust fans if glovebox exhaust fans are inoperable, the dissolver is operated with the charge chute cover off and inaccessible.

With the charge chute cover off, the pressure in the dissolver is very close to the pressure in the glovebox because of the large flow area in the dissolver charge chute. It is not practical to confirm dilution flow by measuring dissolver pressure. Other methods are used to ensure the credited dilution flow is present in the dissolver during the dissolution cycle.

2.1 Dissolver Vessel Vent Design

References 1 and 2 show the vessel vent system connection to dissolvers RD-13 and RD-14 respectively. The connection is a 2-inch P132 pipe (Schedule 10S) that leads from the dissolver to the vent condenser. This pipe is 304L. Outside the gloveboxes, this pipe is jacketed with a 3-inch pipe.

Reference 3 shows the piping connections to the vent condenser. There is a dedicated vent condenser for each dissolver. This is a tube-in-shell heat exchanger, with air and vapor from the dissolver flowing through the tube side and Freon coolant on the shell side. Air and vapor enter the top side of the tubes, and air and condensate exit the bottom side of the tubes. The condenser exit line is also 2-inch Schedule 10S 304L pipe. The exit pipe drops downward before rising upward again. A 1/2 inch tube connects the condenser outlet pipe to the condenser inlet pipe. Condensate from the condenser is passed back to the condenser inlet pipe through this tube and the condensate is returned to the dissolver by gravity.

The condenser exit line goes to the vessel vent catch tank (Reference 4). Before reaching the catch tank, the two 2-inch lines are combined into a single 3-inch line. Other feeds, such as the Phase I and Phase III vessel vent systems, also enter the vent catch tank. The vessel vent system exits the vessel vent catch tank through a demister and a four-inch line.

The vessel vent system then proceeds to the vessel vent system scrubbers (Reference 5). There are two redundant scrubbers. The vessel vent line enters a scrubber through an aspirator (jet) powered by a submersible pump in the scrubber vessel. The system contains valves such that either scrubber can be used or both scrubbers can be bypassed, or that the system can be isolated from the glovebox exhaust plenum. The aspirator provides motive force (in addition to the glovebox exhaust fans) for the vessel vent suction when operating.

The vessel vent system then exits the scrubbers, via a 4-inch line, to the 20-inch glovebox exhaust plenum (Reference 6). This exhausts through a set of HEPA filters to another 20-inch line that connects to the inlet of the two Phase I glovebox exhaust fans. These feed through a 16-inch by 48-inch stainless steel duct inside the HB-Line concrete exhaust duct to the warm canyon air tunnel (Reference 7).

2.2 Potential Flow Interruption Mechanisms

Airflow through the dissolvers can potentially be interrupted by blocking the vessel vent flow path through the dissolvers. There are three potential sources of blockage as discussed below.

If the 1/2-inch line that returns condensate to the dissolver from the vent outlet becomes blocked such that the amount of condensate produced cannot be returned to the dissolver, the condensate could accumulate in the exit line to the extent that it blocks air flow to that dissolver (other parts of the vessel vent system would not be affected).

If the dissolver charge chute is blocked by a foreign object, the vessel vent system would be unable to draw dilution flow through the dissolver (other parts of the vessel vent system would not be affected).

If the valves to both scrubbers and the bypass valve around the scrubbers (three valves) are closed simultaneously, or the downstream butterfly valve is closed, airflow through the vessel vent system would be blocked and the dissolvers would lose dilution flow (all parts of the vessel vent system would be affected). If the valves were closed, vacuum instrument PI-78 would read atmospheric pressure to within instrument uncertainty.

3.0 Evaluation of Potential Flow Blockage Mechanisms

3.1 Inadequate Condensate Return to the Dissolver

The 1/2-inch pipe that returns condensate to the dissolver from the condenser outlet line is called the "P-trap." There is a U-bend in this pipe to maintain a liquid seal between the condenser inlet and the condenser outlet. The P-traps use a 4-inch diameter U section for the liquid seal. The bottom of the liquid seal is four inches below the entry point to the condenser inlet line. This avoids air and vapor bypassing the condenser to flow through the P-trap. The P-traps are shown schematically in Reference 3. More detail is given in Reference 8. The P-traps have a 0.049-inch wall thickness. The exit point from the condenser exit line is one inch higher than the entry point into the condenser inlet line.

This provides a driving force to transfer the condensate from the condenser exit to the condenser inlet line.

3.2 Required Flow Rate Through the P-Trap

The dissolvers are heated with three heating elements of three kilowatts each, for a total of nine kilowatts heat input (Reference 9).

The amount of solution evaporated for a given input of heat can vary with the concentration of nitric acid in water, since the heats of vaporization per unit mass for nitric acid and water differ significantly. If more solution is evaporated, there will be more condensed liquid that must flow through the P-trap to avoid plugging the condenser exit line with condensate. The pressure drop of the liquid flowing through the P-trap also depends on the density and viscosity of the condensed liquid.

For a given heat input, the amount of liquid that will boil depends on the latent heat of vaporization. Reference 10 used the heats of vaporization for the pure components and the mole fractions of the components to calculate the heat of vaporization of nitric acid and water solutions. Equation 1 below is Equation 23 of Reference 10.

$$H^{SL} - H^{SV} = -\Sigma x_i * \Delta H_{vi} \qquad \text{Eq. 1}$$

Where:

H^{SL} = enthalpy of saturated liquid
H^{SV} = enthalpy of saturated vapor
x_i = liquid phase mole fraction of species "i"
ΔH_{vi} = latent heat of vaporization for species "i"

The latent heat of nitric acid is 39.46 kJ/gram-mole, and the latent heat of water is 40.66 kJ/gram-mole, from Reference 11 (page 6.129). The molecular weight of nitric acid is 63, and the molecular weight of water is 18. When converted from kJ to BTU and from gram-moles to pounds, the latent heat of vaporizations is 269.5 BTU/pound for nitric acid and 972 BTU/pound for water.

Equation 1 is not exact, and its accuracy can be improved by iterating on the solution density to achieve the best fit for the density of the boiled solution as a function of molarity. However, the accuracy when no iteration is used is sufficient to determine what molarity acid results in the highest pressure drop when the condensed vapor flows through the P-trap.

For pressure drop calculations, the density and viscosity of the liquid needs to be known. Reference 12 contains correlations for density and viscosity of nitric acid/water systems as a function of nitric acid concentration. These correlations are as follows.

$$\rho = 1.128E\text{-}06M^3 - 6.813E\text{-}04M + 9.947E\text{-}01 \qquad \text{Eq. 2}$$

Where:

ρ = density of solution, grams/milliliter
M = concentration of nitric acid, moles/liter

And

$$\mu = -4.48E\text{-}04M^3 = 9.10E\text{-}03M^2 + 3.40E\text{-}02M + 9.69E\text{-}01 \qquad \text{Eq. 3}$$

Where:
μ = viscosity of solution, centipoises
M = concentration of nitric acid, moles/liter

The pressure drop of liquid through the flow trap depends on the friction loss in the P-trap due to flow. The friction loss is a function of the Reynolds Number, which is a dimensionless parameter composed of viscous forces and inertial forces. In convenient units, the Reynolds Number is as follows (Reference 13, Equation 5.102).

$$N_{Re} = 123.9 * d * v * \rho / \mu \qquad \text{Eq. 4}$$

Where:

N_{Re} = Reynolds Number, dimensionless
d = internal diameter of pipe, inches
v = velocity of fluid, feet/second
ρ = density of fluid, lbs mass/cubic foot
μ = viscosity of fluid, centipoises

The factor of 123.9 includes the unit conversions needed for the units used.

The velocity of the fluid in the P-trap is needed to calculate the Reynolds Number. The dissolver heaters have three tubular heating elements, each with a rated power output of three kilowatts (Reference 9) for a total output of nine kilowatts. It is assumed that eight kilowatts of the heaters heat liquid in the dissolver and one kilowatt is lost from the sides and top of the dissolver. This amount of heat input is used with Equation 1 to calculate the pounds of solution evaporated per unit time, using the conversion factor of one kilowatt equaling 0.9431 BTU/second (Reference 13). This can be converted into cubic feet per second using the factor of 62.4 pounds-mass water at 20 °C and the calculated density in grams/cc from Equation 1. The velocity is then obtained by dividing the volumetric flow rate by the cross-sectional area of the P-trap. The results are shown in the Velocity column of Appendix A.

The Reynolds Number of the fluid in the P-trap is then calculated using Equation 4 and the result is shown in the Reynolds Number column in Appendix A.

Note that the Reynolds Numbers are low (maximum about 450) which shows the flow through the P-trap is laminar. This is expected with the small driving force (one inch of the liquid) for flow through the P-trap.

When the Reynolds Number is low, the following equation applies (Reference 13, Equation 5.38).

$$f = 64/N_{Re} \qquad \text{Eq. 5}$$

Where:

f = Moody friction factor, dimensionless
N_{Re} = Reynolds Number, dimensionless

When the friction factor for flow is known, the pressure drop due to flow through the P-trap can be calculated from the Darcy equation as follows (Reference 13, Equation 5.37).

$$\Delta p' = \rho * f * L * v^2/(144*2*D*g_c) \qquad \text{Eq. 6}$$

Where:

Δp' = pressure drop, psi
L = length of P-trap, ft
D = internal diameter of pipe, square feet
g_c = 32.2 lbs force-ft/(lbs mass-sec^2)

All other terms are as previously defined.

As previously discussed, the P-trap is one inch higher on the condenser outlet side (where the condensate collects) than on the condenser inlet side (this is connected to the dissolver). The one inch of head drives the condensate from the condenser outlet line back to the condenser inlet line. The U-trap is two inches radius. The elevation from the start of the U to the pipe connection is about two inches on the condenser out side and 1 inches on the condenser inlet side. The total length of the vertical part of the P-trap is thus (π*2 inch) + 1 + 2 = 9.28 inches. This is rounded up to 12 inches, or one foot, to account for the horizontal portion of the P-trap where the P-trap enters the condenser inlet line. With this factor, Equation 6 can be used to calculate the pressure drop through the P-trap.

Further, the pressure drop can be converted from psi to inches of water column (WC) by noting that one atmosphere is 33.9 feet of water or (33.9*12) = 406.8 inches WC, and one atmosphere is 14.696 psi. The conversion from psi to in WG is thus obtained by multiplying psi by (406.8/14.696) = 27.67 in WC/psi.. This result is shown in the column labeled "deltaP in WG" column in Appendix A.

This column shows that the pressure drop through the P-trap is low (less than 0.03 inches WG at the maximum). It also shows that the pressure drop for the high molarity solution is about twice the flow rate for the lowest molarity solution (pure water is assumed, but process water would be about the same). This is because the flow is laminar, and the increase in pressure drop is because of the increase in viscosity for the high molar solution. Per this information, a 14M solution would flow only half as fast as a 0M of nitric acid.

The driving force for flow increases as the density of the solution goes up, since the driving force is a one inch high column of the condensate. As the density of this column increases, the driving force for flow increases. This tends to cancel out some of the increases in friction when evaluating the effect of the P-trap to return condensate to the dissolver. When the pressure drop is adjusted for the density difference, a 0M solution flows only about (2.06/1.46) = 1.41 times as readily as a 14M solution.

This analysis shows that a 14M solution is more likely to be restricted in flow than are lower molarity solutions. If restrictions in the P-trap flow area do not result in condensate backup (and blocked vent airflow) for 14M solutions, solutions of lower molarity have some flow margin left before causing condensate backup.

Equation 6 reduces to the Poiseuille equation (Reference 8, Equation 5.39) for laminar flow conditions. This is stated below.

$$\Delta p' = 0.000668 * \mu * L * v / d^2 \qquad \text{Eq. 7}$$

All terms have been previously defined.

The minimum diameter P-trap that could handle the amount of 14M nitric acid that is boiled by 8 kW of heat can be estimated from this equation. The right-hand side of the equation is multiplied by 27.67 to convert the pressure drop to in WG. Since a one-inch column of fluid is the driving force, the allowable pressure drop is adjusted for the higher density of fluid by multiplying by the density of 14M acid, which is 1.38 at ambient temperature. Then, it is seen that the velocity of the fluid in the P-trap, for the boiling rate resulting from 8 kW of heat input, is the volumetric flow rate divided by the cross-sectional area of the pipe. This is (1.9E-04 ft^3/second)/(0.785*$(d/12)^2$ ft^2) = $0.0349/d^2$ feet per second. With a viscosity of 2.0 centipoises and a trap length of one foot, Equation 7 reduces to the following sequence.

$$1.38 = (0.000668*27.67*2.0*1.0*(0.0349/d^2))/d^2$$

This reduces to d^4 = (0.0349/37.33) =9.35E-04, and d = 0.175 inches.

This number has significant uncertainty. It is instructive that the 0.41 inch diameter P-trap can be significantly constricted before condensate is expected to build up and block airflow through the system.

3.3 P-Trap Potential Plugging Mechanisms

3.3.1 P-trap Performance History

Per discussions with experienced personnel, none remembered occurrences of plugged P-traps during the 1980's or 1990's. Low-molar boilups (details discussed later in this document) were implemented in the 1980's because of concerns relative to condenser performance, but there is no memory of incidents of P-trap pluggage in this time frame. Boilups are performed by loading the dissolver with acid solution only and vigorously heating the solution to create vapor and condensate in the condenser. Per memory of key personnel and examination of the STE daily log, there has been a single occurrence since 2000.

The North Line of Phase I has operated since early 1987 (about 19 years).

The single occurrence of a plugged P-trap in the history of Phase I operations was in February 2005. The pluggage occurred in the P-trap associated with RD-14. There have been no known P-trap pluggages in the P-trap associated with RD-13, and the operational history of both dissolvers is similar.

A charge was placed in RD-14 in late December of 2004. Due to problems with the Freon unit and the dissolver level indication, this charge was not processed for ~ 40 days. The dissolver inadvertently dried out during this time. A camera inspection revealed the presence of a powdery material in the bottom of the dissolver. There was a mound of material visible around the dissolver agitator, indicating the agitator may have operated after the material had dried out. The P-trap required cleaning before the dissolver was restarted due to loss of vacuum to the dissolver.

This event occurred while the dissolver was being operated with the charge chute cover available and a hole drilled in the cover to allow glovebox air to be drawn into the dissolver for hydrogen dilution (under the TSR). There have been no occurrences of plugged P-traps while operating with the dissolver charge chute cover not available.

3.3.2 Potential P-trap Plugging Methods

The P-trap can plug if solid material collects in the trap to fill the tube. The tube is 1/2 inch outside diameter with 0.049-inch walls, for an internal diameter of 0.41 inches. The mechanisms considered for solid material collecting in the P-traps include transportation of soluble material with subsequent precipitation in the P-trap and direct transportation of solid material to the P-trap.

The P-trap does not have to completely plug to cause flow interruption. Flow through the trap has to be plugged such that not all the liquid condensed can pass through the P-trap and will collect in the exit line to a height sufficient to block the airflow out this line.

Flow blockage could be intermittent in that additional condensate will not form when airflow is interrupted and condensate in the outlet line will slowly drain to the extent airflow can be temporarily reestablished.

3.3.2.1 Direct Transportation of a Solid Object to the P-Trap

A solid object with a diameter greater than the ID of the P-trap can't be transported from the dissolver through the condenser to the P-trap. The tubes in the condenser are 3/8-inch OD and 0.049-inch wall. The ID of the tubes is thus (0.375-0.098) = 0.277 inches which is smaller than the P-trap ID. Also, the air and vapor flow is much too low in velocity to transport solid objects upward.

3.3.2.2 Transport of Material from the Dissolver to the P-trap

Transport of both solid material and soluble material is considered below.

3.3.2.2.1 Transport of Solid Material from the Dissolver to the P-Trap

The 2-inch condenser entry line rises more than five feet between the dissolvers and the condensers. Vapor and air are drawn up this line by the motive force of the glovebox exhaust fans and the scrubbers. Finely-divided particulate solids, such as dust, may be transported up the vent line to the condenser, then transported by the condensate to the P-trap as either dissolved or entrained solids. No air passes through the P-trap, so the velocity is lower than in the entry and exit lines. Particulate material may settle out in the low flow region of the P-trap. Over time, enough material might build up to block the 0.41 inch diameter of the P-trap.

The air for the dissolver purge is drawn from within the gloveboxes. Glovebox air is drawn from the rooms holding the gloveboxes, and the air entry points into the gloveboxes contain HEPA filters. Air entering HB-Line is also filtered.

Over long times, fine dust may penetrate all the filters and be drawn into the condenser through the vent line. The dust may deposit in the condenser and then be washed down into the P-trap. When the dissolvers aren't in active use, the P-trap water is stagnant giving a long time for solid material settling. Then, fresh liquid introduced during condensation of the next dissolver charge will wash residual material out of the P-trap, if the material has not solidified. This mechanism may explain the long time the P-traps operated without plugging.

Another method of generating dust fines that could be transported to the condenser and P-trap is to allow the dissolvers to dry out and continue to be agitated and heated, thus potentially generating some fine solid material that would suspend and be transported to the condenser and P-trap. Dissolver temperature is slightly elevated, when not dissolving, to keep the heating elements dry. A visual examination of RD-14 in early 2005 indicates that the dissolver dried out while the agitator continued to run and a plugged P-trap was found shortly thereafter.

3.3.2.2.2 Transport of Soluble Material from the Dissolver to the P-trap

Chemical species that are soluble in atmospheric-pressure steam can be transported from the dissolver to the condenser when the dissolver is boiling. These species could then plate out in the condenser, re-dissolve partially in the condenser with condensate, and be transported to the P-trap in condensate. When there is no flow through the P-trap over a period of time, the water in the P-trap could evaporate causing the soluble material to precipitate out.

Another mechanism where soluble species may be transported to the condenser is through foaming. If the solution foams and the height rises to the vent condenser, some of the foam may be transported up the condenser inlet line to the condenser. It could then be transported through the condenser directly. More likely, the material would plate out on the condenser tubes when the vapor is cooled, then be re-dissolved by condensate and transported to the P-tube by condensate. Then, some may precipitate out of the water that remains in the P-trap when condensate is no longer being produced in the dissolver, by partial evaporation of the remaining water. Foaming is not expected in the dissolvers, but cannot be precluded.

High airflows across a water surface can create mists. These mists could be transported up the vent tube to the condenser. The flow velocity across the dissolver liquid surface is, by itself, too low to create significant waves that are required to generate mists. However, the dissolver is continuously stirred during dissolution, and the combination of the stirrer and airflow might create mists.

Sodium and silica show significant steam transport (between boilers and turbines) with high–pressure steam. This would not be expected for atmospheric pressure saturated steam. Experience supports that aluminum nitrate (added in solution after dissolution to complex the fluoride for corrosion protection of downstream tanks) may be transported to the condenser and then to the P-trap which may lead to pluggage.

When liquid is being condensed in the condenser, and then is being sent back to the dissolver via the P-trap, the concentration of nitric acid in the condenser does not change over time. When condensation is not perfect, it is expected that more water will escape condensation than will nitric acid. This will lead to increased nitric acid concentration in the dissolver.

Aluminum nitrate is more soluble in low concentration nitric acid than in high concentration nitric acid. A saturated solution of aluminum nitrate in nitric acid left in the P-trap between dissolutions may cause some precipitation of aluminum nitrate when the liquid begins to evaporate. Water will evaporate preferential to nitric acid and the acid concentration of the liquid will increase. Repeated cycles over time could cause solids buildup. Boiling low concentration nitric acid in the dissolver will transport low-molarity nitric acid to the condenser and P-trap. If aluminum nitrate solids are present, the low-molarity boilup should remove some or all of them. Low molar boilups have been previously instituted as a preventive action for P-trap pluggage.

3.3.2.3 Material From Other Than the Dissolver

3.3.2.3.1 Material Originating from Condenser

All condenser materials are stainless steel to avoid corrosion and generation of solid corrosion products. However, over long times, a low corrosion rate can generate a significant amount of solid corrosion products. The condenser tubes have a large surface area relative to the other system components. Solid corrosion products would be transported to the P-trap by condensate and could settle out in the low-flow zone.

This could explain the long time from starting dissolver operation in the 1980's to plugging one P-trap in 2005. Corrosion is low, and collection of solids from this corrosion would be slow.

3.3.2.3.2 Material Originating from Pipes

The surface area of pipes are less than the surface area of condensers in this system. Also, solid corrosion products formed on the pipes would have to be transported upward to eventually enter the P-trap. Further, a camera inspection of the inlet piping in 2003 did not show any significant corrosion products in the pipe. The contributions from the condenser would far outweigh the contributions from pipes.

3.4 Dissolver Charge Chute Plugging

3.4.1 Potential Charge Chute Plugging Mechanisms

The charge chute could be plugged by placing an object larger than five inches in diameter on top of the charge chute. This could include a charge chute cover, a charging beaker, or other large solid object across the top of the dissolver charge chute.

The charge chute could be plugged by a large solid object between five inches in diameter and three inches in diameter being placed in the top part of the charge chute.

The charge chute could be plugged by flexible material being placed on the top of the charge chute, then being drawn partially into the charge chute by the vacuum exerted by the vessel vent system.

The charge chute could be partially plugged and decrease flow below what is credited when the sample basket is left in the charge chute when withdrawn from the dissolver.

3.4.2 Evaluation of mechanisms

A visual check that there is no material in the top portion of the charge chute (the three inch to five inch pipe expander) is sufficient to verify the charge chute is not significantly obstructed, for the reasons discussed below.

Rigid and/or semi-rigid material such as a glovebox glove, charge chute cover, or charging bottle, will be at the top of the charge chute. Any rigid material that could go below this point would fall through the charge chute into the dissolver, assisted by the vacuum in the charge chute.

Flexible material such as plastic bags or paper wipes may crumple slightly and pass from the pipe expander into the pipe. Light material may not fall readily through the charge chute but would be assisted by the vacuum in the charge chute. Further, when the material to be dissolved is poured into the charge chute, the weight of the charge will force the flexible material to pass through the charge chute into the dissolver.

The charge chute is not the limiting point for the dilution flow. The dilution flow must pass through the tube side of the condenser and the ventilation pipe connecting the condenser to the dissolver. The condenser has 34 tubes that are 0.375 inch OD with a 0.049 inch wall (Reference 14). The cross-sectional area available for air flow through these tubes is about 2.05 square inches. The ventilation pipe is two inch Schedule 10S; its cross-sectional area is about 3.65 square inches. The smallest section of the charge chute is three inch Schedule 40 pipe; its cross-sectional area is about 7.39 square inches. The charge chute, at its smallest point, has a cross-sectional area over three times the cross-sectional area of the condenser tubes. Minor blockage of the charge chute will not significantly degrade the credited dilution flow.

The charge basket may be suspended in the charge chute temporarily. The charge basket has a diameter of two inches; its crosssectional area is $(0.785)*(2)^2 = 3.14$ square inches. The charge chute is Schedule 40 SS pipe; it has a 7.393 square inches (Reference 13) crosssectional area. The remaining flow area with the charge basket in the charge chute is $(7.393 - 3.14) = 4.253$ square inches. This is about twice as large as the crosssectional area for flow through the condenser tubes, so the effect of the charge basket in the charge chute on dilution flow will not be significant.

The typical amount of liquid in the dissolver before a charge is made is 17 liters. The liquid level surface is about six inches below the top of the dissolver, and width of the dissolver tank is 3.25 inches. This provides an area for airflow through the top of the dissolver of about 19.5 square inches. This is about a factor of three greater than the charge chute area. For a 50 cfm flow rate through this area (the maximum flow measured during the flow tests) the flow velocity is about 6.2 feet/second. This converts to about four miles per hour. This velocity is not high enough to move anything other than very light material (such as paper) across the top of the dissolver. The velocity of 50 cfm airflow through the charge chute is about 11 miles/hour, and the momentum of a flexible object when it exited the bottom of the charge chute would direct the object to the liquid surface.

3.5 Simultaneous Closure of Bypass Valve and Both Scrubber Inlet Valves

Vessel vent air enters a scrubber at a liquid aspirator powered by a submersible pump in each of the scrubbers. Each scrubber inlet contains a valve (V-785 and V-786, respectively). The inlet valve is open to the operating scrubber and closed for the alternate scrubber. Additionally, there is a ball valve (V-784) on the scrubber bypass line. This valve is normally closed and is opened only when both scrubbers are to be bypassed.

If all three of these valves are closed simultaneously, the vessel vent flow is blocked. This could occur when scrubbers are being swapped if the valve to the in-service scrubber is closed before the valve to the alternate scrubber is opened.

The flow measurement that is credited for dissolver dilution flow were taken with the scrubber pump off and flow through the inactive scrubber as a higher pressure drop than when the system is in bypass, to provide a bounding measurement of dilution flow. The case of a scrubber pump being inadvertently taken out of service, or failing, is bounded by the measurement conditions.

There is an additional valve (V-780) on the vessel vent line downstream of where the scrubber flow returns to the vessel vent system. This valve is a butterfly valve. It is inaccessible unless ladders or scaffolding is used to access the valve. It is normally open. If this valve is closed, the vessel vent system flow is blocked.

Controls are needed to ensure that V-780, and at least one of V-784, V-785, and V-786 are open when chemical hydrogen is being generated in a dissolver.

4.0 Program Elements

Methods to ensure the dissolver flow is maintained at least at the value credited for hydrogen dilution are discussed here. Currently, there is insufficient information to reject any of the proposed mechanisms as invalid, even though the long time of operation before P-trap pluggage make some of the proposed mechanisms for P-trap pluggage unlikely.

4.1 Controlling P-Trap Pluggage

4.1.1 Ensure P-traps for the condensers for both dissolvers are not blocked

It is important to clear partial blockage as just limiting the flow, rather than blocking it completely, may cause airflow interruption.

One method of ensuring this would be to remove the P-traps and rod them thoroughly. This could also be done by changing out the existing P-traps for new P-traps that are verified to be clean. This ensures airflow to the dissolvers is not blocked regardless of the mechanism. This should be performed periodically, at a frequency to be established through an engineering evaluation per the E7 manual. When combined with recommendations on low molarity boilup in 4.1.3 below, or more frequently if special events such as dissolver dryout with the agitator operating occurs as discussed in 2.5.4 below, a long interval is expected. The long time from initial operations to the first plugged P-trap justifies a long test interval.

An alternative method to ensure short-term P-trap performance is to test the ability of the P-trap to allow sufficient condensate flow to avoid collecting a significant amount of condensate in the condenser outlet pipe. High molar nitric acid can be introduced to the P-trap by boiling a high molar nitric acid solution in the dissolver. Flow through the P-trap can be accomplished by performing a high-molar boilup of the dissolver with airflow measurements in the dissolver to ensure airflow is steady and has not significantly degraded. As shown in Appendix A, if a 14 molar solution can be handled without P-trap pluggage, lower molar solutions will pass at a higher flow rate. The frequency of this boilup should be performed at a frequency to be established through an Engineering evaluation per the E7 Manual. The type of material being charged should be considered when establishing the verification frequency. This method does not ensure the P-trap is completely clean, so it is expected it would be performed more frequently than rodding or P-trap replacement. It is apparent that the maximum heater power that can be safely used should be used during this boilup, if this method is chosen.

Based on the available data, either of these methods ensures the P-traps will not cause the condensate lines to plug regardless of the mechanism.

4.1.2 Evaluate adding aluminum nitrate to the PHT rather than the dissolver.

Currently, aluminum nitrate is added to the dissolver immediately before cooldown and transfer to complex the fluoride and lower corrosion in downstream tanks. It can be added directly to the Product Hold Tank (PHT) and still lower corrosion in downstream tanks. The PHT's are not connected to the condenser, so this would eliminate potential aluminum nitrate transfer to the condenser. This puts the piping and components used to transfer solution between the dissolver and PHT at risk for additional corrosion since the fluoride will not be complexed during this transfer. That risk is considered reasonable until the mechanism for P-trap pluggage has been proven not to be associated with aluminum nitrate addition to the dissolvers.

This is effective if the problem is carryover of aluminum nitrate to the condensers. If the sample results for material removed from the RD-14 P-trap indicate that aluminum nitrate is not a pluggage issue, adding aluminum nitrate to the dissolver will be re-evaluated.

4.1.3 Perform a low-molarity boilout to clean aluminum nitrate from condenser and P-trap

Aluminum nitrate is more soluble in low molarity nitric acid than in high molarity nitric acid. Other nitrate salts may behave similarly. Boiling the dissolver with low molarity nitric acid in it effectively transfers condensed low molar nitric acid to the P-trap and part of the condenser. If aluminum nitrate is the cause of P-trap blockage, there could be residual material on the condenser from years of operation that has not yet been moved to the P-trap. This would remove the hazard in a semi-controlled fashion.

When material that contains a significant amount of aluminum is dissolved, the low molar boilup will be performed more frequently

4.1.4 Avoid dissolver dryout when significant material is in the dissolver

Powdery solids generated when a charged dissolver was inadvertently dried out is a potential cause of the single incident of P-trap pluggage. This recommendation prevents formation of small solids particles that are easily made airborne and transportable to the condenser. Most material charged to the dissolver is dissolved during a dissolution cycle and is transferred to the PHT while in solution. The amount of material remaining in the dissolver heel after transfer is small, and does not have as much potential to generate powdery material that can be transferred to the condenser.

If a dissolver is inadvertently dried out while containing a charge, a detailed Engineering evaluation per the E7 Manual should be performed. Actions necessary to ensure the associated P-trap is not plugged before another dissolution cycle in that dissolver should be identified and performed before further dissolutions are performed in that dissolver.

4.1.5 Evaluate lowering the temperature of the heater elements between dissolutions

This recommendation is a good practice, based on the postulated mechanism of generating small powders if the dissolver is dried. It would lower the energy source for getting into this condition. The recommendation may be terminated if the mechanism is found to be aluminum nitrate transport.

4.2 Ensure the Dissolver Charge Chute is Not Blocked Before Charging

A visual examination of the upper part of the charge chute should be performed before each dissolver charge. As previously discussed, inspection of this part of the charge chute is adequate to ensure there is no significant blockage in the charge chute that would degrade the dilution flow to below the value credited for dilution.

4.3 Ensure the Vessel Vent Scrubber Valves are not Blocking Vessel Vent Flow

As previously discussed, closing the vessel vent entry valves to both scrubbers and the scrubber bypass valve simultaneously will block all airflow through the VV system. Closing the butterfly valve downstream of the scrubbers will also block dissolver dilution flow. Operation of these valves is procedurally controlled. These valves are located in a room that is frequently contaminated and will require RCO assistance to enter, so personnel do not routinely go into this room unless they have a specific task to perform in the room. The butterfly valve is operated by chain (the valve is in a normally inaccessible position) and the other valves are accessible from the floor.

5.0 Assumptions

An experimental uncertainty of 33% is assumed when evaluating the flow data taken in Reference 2. This uncertainty is applied since the data is used to establish conditions to prevent an energetic event. By design, the flow rate through the two dissolvers, with the charge chute covers removed, should be the same. This is true when the motive force for air drawn through the chutes is the vessel vent system or the H-Canyon exhaust fans. Therefore, the flow rate established in Reference 2 is treated as an average of two readings. Further, the value for the flow through each individual dissolver charge chute is the result of five separate measurements per dissolver. This provides a more robust measurement of the flow than if a single measurement had been made for each dissolver.

Further, the flow for the normal case was made with the scrubber off. This provides additional conservatism for the flow assumed for normal dissolution.

The flow through the dissolver charge chute, when the HB-Line Phase I glovebox exhaust fans are operating, is not significantly affected by the H-Canyon fan configuration. The glovebox exhaust fans provide the major part of the motive force for dissolver flow during this condition.

Any combination of three H-Canyon exhaust fans are sufficient to provide the flow credited in this document when the HB-Line Phase I glovebox exhaust fans and scrubbers are not operating. Each fan has an inlet damper. These dampers are adjusted such that the vacuum in the H-Canyon exhaust tunnel is the same (1.8 inches water gage ± 0.1 inches water gage) for any combination of three H-Canyon exhaust fans.

The assumed uncertainty of 33% is conservative for the procedure used to measure the flow.

The latent heat of nitric acid and water mixtures can be approximated by multiplying the latent heat of each pure component by the mole fraction of the component in the mixture. Large deviations would modify some of the quantitative results in this document, but would probably not change the conclusion that a high molar boilout provides the highest challenge to P-trap flow capability.

6.0 Discussion

The mechanisms for dilution flow degradation from mis-positioning the scrubber system valves and blocking the dissolver charge chute are straight forward. Administrative controls on valve operation can prevent valve mis-alignment, and periodic surveillance can ensure that the valves are properly aligned. Charge chute inspection before charging the dissolver to ensure visually that the top part (down to the three-inch pipe) of the charge chute is not blocked resolves this issue.

The VV piping leading from the dissolver to the glovebox fan exhaust header is two-inch or greater. It is difficult to postulate a short-term mechanism for plugging this piping through routine dissolver operations. Periodic verifications that the dissolver flow has not degraded should be sufficient to ensure the flow area in these pipes is not degrading to the point where dilution flow would be below the credited value.

There are 24 tubes in each condenser that have an ID of 0.277 inches. It is difficult to postulate a short-term mechanism to plug the condenser such that dilution flow was degraded below the credited value. Heat transfer would be significantly degraded before there was significant effect on flow. Monitoring the heat transfer characteristics of the condensers periodically should provide an advance sign that dilution flow may be subject to future degradation due to condenser fouling.

There is insufficient evidence to identify the mechanism for plugging the P-trap for RD-14 in 2005, although dissolver dryout while a charge was present in the dissolver strongly indicates that dryout enhances a pluggage mechanism. Samples of the material removed from the P-trap were still available, and they have been submitted for laboratory analysis. The data from this analysis will strengthen the viability of some mechanisms but may not be sufficient to identify a single mechanism for P-trap pluggage. Longer-term trending of operating parameters such as condenser performance may be useful in identifying the P-trap plugging mechanism.

7.0 Recommendations

Continue the visual check of the upper part of the dissolver charge chute for material that may plug the charge chute before each charge is made.

If determined to be needed, strengthen the administrative controls on valve positioning for the scrubber system.

Evaluate the analytical results from the material removed from the RD-14 P-trap when it plugged. Document the evaluation per E7 manual methods to ensure the evaluation is technically sound and is retrievable in the future.

Continue methods that would prevent/mitigate all proposed P-trap pluggage mechanisms unless some proposed mechanisms are shown to be not applicable in the future.

Include an evaluation of the frequency of applying P-trap preventive/mitigative methods in the E7 evaluations required by TS 6.4.17.4.b.

For the longer term, evaluate dilution methods that do not depend on the P-traps passing condensate back to the dissolver to maintain dilution flow. Introducing purge flow through the dissolver charge chute with a charge chute cover designed to seal the charge chute against outleakage to the pressure greater than the static pressure of the height of the water column between the condenser outlet and the vessel vent system would ensure dilution flow even if the P-trap plugged. This could also subject the dissolver to pressures in excess of design, so the effect on the dissolver would have to be evaluated. Since the dissolver has been shown to not bulge sufficiently to create a criticality potential for pressures above 100 psi, the issues with pressurizing the dissolver to pressures greater than the column of water discussed above should be operational and not safety.

8.0 References

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2.0 W715621, Rev. 122, *Dissolver Wing Cabinet # 7, Piping Diagram Sht. 3, Process & Instruments-North Line (U)*

3.0 W715627, Rev. 152, *Vent Condenser Piping Diagram (Sh9), Process & Instruments North Line*

4.0 W710580, Rev. 104, *Vessel Vent Piping Diagram Process & Instruments (U)*

5.0 M-M6-H-2373, Rev. 0, *Vessel Vent System, P&ID (U)*

6.0 W715203, Rev. 52, *Glove Box Air Flow Diagram, Heating and Ventilation*

7.0 W710831, Rev. 7, *Duct Connection to Warm Canyon Exhaust Tunnel Heating and Ventilating*

8.0 W719069, Rev. 48, *Vent Condenser Piping Arrangement, Process & Instruments, Sh. 2*

9.0 W717622, Rev. 21, *Dissolver Heater H362-100-2/H362-200-2 Equipment Assembly Process & Electrical*

10.0 F-CLC-H-00121, Rev. 1, *HB-Line Fourth Level Fire Severity Evaluation*, 4/24/02

11.0 Dean, John A., *Lange's Handbook of Chemistry*, Fifteenth Edition, McGraw-Hill

12.0 WSRC-TR-2001-00361, *Orifice Selection for HB Line Phase II Eductor Systems*, J. L. Steimke

13.0 Robinson, Randall N., *Chemical Engineering Reference Manual for the PE Exam*, Fifth Edition, Professional Publications, Inc., Belmont, California

14.0 BPF213565, *Four Dissolver Vent Condensers*, Order AXC 2903-W, Excelco Developments, Inc. ,4274 Mill Street, Silver Creek, NY 14136, 3/11/82

Appendix A: Flow Characteristics of Condensate Through The P-Trap

			Mole	Mole.	Heat of	Boiloff at	Boiloff at	Velocity	Reynolds	deltaP	Adj.
HNO3	Density,	Viscosity,	Fraction	Fraction	Vap.,	8 Kw,	8 Kw,	in P-trap,	# in	in WG	Driving Force
Molarity	gm/cc	centipoises	HNO3	H2O	BTU/lb	lbs/sec	ft3/sec	ft/sec	P-trap		For Density
0	0.99	0.97	0.00	1.00	972.0	7.76E-03	1.25E-04	1.36E-01	444	1.46E-02	1.46E-02
1	1.03	1.01	0.02	0.98	959.2	7.87E-03	1.22E-04	1.33E-01	431	1.49E-02	1.44E-02
2	1.07	1.07	0.04	0.96	946.1	7.97E-03	1.20E-04	1.31E-01	413	1.54E-02	1.44E-02
3	1.10	1.14	0.06	0.94	932.7	8.09E-03	1.18E-04	1.29E-01	393	1.61E-02	1.47E-02
4	1.13	1.22	0.08	0.92	918.9	8.21E-03	1.16E-04	1.27E-01	372	1.71E-02	1.51E-02
5	1.16	1.31	0.10	0.90	904.6	8.34E-03	1.15E-04	1.25E-01	353	1.81E-02	1.55E-02
6	1.19	1.40	0.12	0.88	889.8	8.48E-03	1.14E-04	1.24E-01	335	1.92E-02	1.61E-02
7	1.22	1.50	0.14	0.86	874.3	8.63E-03	1.13E-04	1.24E-01	319	2.04E-02	1.67E-02
8	1.25	1.59	0.16	0.84	858.1	8.79E-03	1.13E-04	1.23E-01	306	2.16E-02	1.73E-02
9	1.27	1.69	0.19	0.81	841.0	8.97E-03	1.13E-04	1.23E-01	295	2.28E-02	1.79E-02
10	1.30	1.77	0.21	0.79	823.0	9.17E-03	1.13E-04	1.23E-01	287	2.41E-02	1.85E-02
11	1.32	1.85	0.24	0.76	803.7	9.39E-03	1.14E-04	1.24E-01	282	2.53E-02	1.91E-02
12	1.34	1.91	0.27	0.73	783.1	9.63E-03	1.15E-04	1.25E-01	279	2.64E-02	1.97E-02
13	1.36	1.96	0.30	0.70	761.0	9.91E-03	1.16E-04	1.27E-01	280	2.75E-02	2.01E-02
14	1.38	2.00	0.33	0.67	737.0	1.02E-02	1.19E-04	1.29E-01	284	2.85E-02	2.06E-02