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		Design Authority									
		Design Agent									
1	1	Cog. Eng. L.J. Julyk	[signature]	9/11/00							
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		QA									
		Safety									
		Env.									

18.	19.	20.	21. DOE APPROVAL (if required)
[signature] A.R. Tedeschi 9/8/00 Signature of EDT Originator / Date	[signature] T.C. Conrads 9/12/00 Authorized Representative for Receiving Organization / Date	[signature] for M.D. Hasty 9/12/00 Design Authority/ Cognizant Manager / Date	Ctrl No. ____ ☐ Approved ☐ Approved w/comments ☐ Disapproved w/comments

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Determination of Secondary Encasement Pipe Design Pressure

A. R. Tedeschi
CH2M HILL Hanford Group, Inc.
Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-99RL14047

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Key Words: double encased, encasement pipe pressure, tank farm

Abstract: This document published results of iterative calculations for maximum tank farm transfer secondary pipe (encasement) pressure upon failure of the primary pipe. The maximum pressure was calculated from a primary pipe guillotine break. Results show encasement pipeline design or testing pressures can be significantly lower than primary pipe pressure criteria.

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RPP-6759
Revision 0

Determination of Secondary Encasement Pipe Design Pressure

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

CH2MHILL
Hanford Group, Inc.
Richland, Washington

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC06-99RL14047

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Revision 0

Determination of Secondary Encasement Pipe Design Pressure

Prepared by:

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Date Published
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Prepared for the U.S. Department of Energy
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Office of River Protection under Contract DE-AC06-99RL14047

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Document Title: Determination of Secondary Encasement Pipe Design Pressure

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for M. D. Hasty, Chief Engineer
CH2M HILL Hanford Group, Inc.

Date

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EXECUTIVE SUMMARY

This document, the *Determination of Secondary Encasement Pipe Design Pressure*, formally issues a calculation of the same subject. The calculation evaluated the maximum internal pressure experienced by the secondary encasement piping during a postulated worst-case primary pipe failure, for standard Tank Farm Contractor transfer piping. The largest encasement pressure calculated was 240 psig for a system with a low point 1-inch diameter drain, and 170 psig for a system with a low point 2-inch diameter drain. These values were calculated for the largest estimated Tank Farm Contractor piping section of 4000 equivalent feet, assuming a primary pipe operating pressure from a 650 psig dead-head pump with run-out flowrate of 285 gpm.

A significant reduction in the encasement pressure can be obtained if both a high and low point drain is provided. Under this condition the maximum encasement pressure was 140 psig with 1-inch diameter drains and 40 psig with 2-inch diameter drains.

The resulting estimated encasement pressure is significantly below standard encasement design pressures, not using mechanical pressure relief. This evaluation may allow the lessening of design or testing pressure limits for future transfer piping. However, the estimated resistance loss factors for the pipe guides, supports, and anchors within the annulus flow region need to be verified. The short text in the body of this report summarizes the calculations, and the detailed calculations are included in the report Appendix.

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APPENDICES

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1.0 INTRODUCTION

Mathematical evaluation of internal secondary encasement piping pressures was performed. Pressures were calculated for several primary piping break scenarios. This evaluation used standard flow and pressure formulas with conservative piping configuration and flow liquid assumptions. This document describes the evaluation results, calculation assumptions and details, and conclusions produced from the data.

2.0 PURPOSE

This evaluation will be used to assist development and modification of future functional design and testing criteria of secondary encasement piping. Currently, secondary encasement piping is designed, fabricated and tested to the pressure requirements of the primary piping. Secondary piping pressure requirements may be lowered by the optional usage of pressure relief or rupture disk relief systems. Project W-314 detailed these options in its transfer piping specifications (McGrew 1999a and 1999b). Primary and secondary piping for this project were to be both designed to 400 psig while tie-in piping to the existing cross-site transfer line utilizes pressure relief. This design strategy is conservative but results in added costs that may not be warranted by worst-case flow and pressure scenarios. In addition to added costs, use of mechanical pressure relief of radioactive streams pose added risk to the environment and operator safety. In addition, encasement pressure testing during construction poses risk to testing personnel from the high air pressures involved, and their close contact needed for visual inspection. Results from this study may allow Design Authorities to reduce pressure requirements for encasement piping.

The results of this study are not applicable to the cross-site transfer line system because of differences in leak detection, transfer pump capacity, and the length of the line.

3.0 RESULTS

Three separate piping configurations were analyzed with different configurations of piping drains relative to the break point: 1.) Pipe sloping up from the pump with an encasement drain on either side of the break, 2.) Pipe sloping up from the pump with a single drain upstream of the break, and 3.) Pipe sloping down from the pump with a single drain downstream of the break. Summary results include the following:

- Maximum encasement pressure from a primary pipe break is 253 psig with a piping section of 7000 feet equivalent length, and 240 psig for a piping section of 4000 feet equivalent length
- Pressure range for the encasement from primary pipe break is 24 psig - 253 psig

- Temperature effects are negligible
- Pressure increases are minimal over the range of probable waste bulk densities
- Increasing pipe section length has no effect on pressure for upward sloping pipe with a low-point drain

The following information is reproduced from the Appendix A, Table 1.

Table 1. Maximum Encasement Pressure (psig) From Primary Pipe Break.

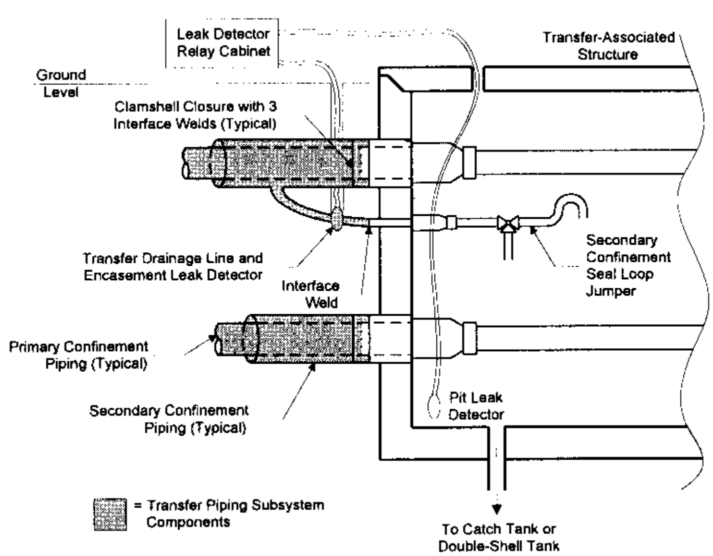
Case	Pipe Slope in Flow Direction	Equivalent Length (feet) of Encasement Section Piping Between Pits			
		1,000	2,000	4,000	7,000
1-inch Drain					
Two Drain	Up	130	134	140	147
Low Point Drain	Up	223	223	223	223
Low Point Drain	Down	221	229	240	253
2-inch Drain					
Two Drain	Up	24	31	40	48
Low Point Drain	Up	78	88	89	89
Low Point Drain	Down	94	127	168	204

Note that the pressure within the encasement piping section, between pits for a postulated primary pipe break, decreases as the distance from the pump increases.

4.0 SYSTEM BACKGROUND

The transfer piping system used for liquid waste transfer within Hanford Tank Farm Contractor facilities is generally comprised of a pipe within a pipe, termed double-encased piping. An interior pipe is used for the actual material transport and is termed primary piping. The outer piping is called secondary piping, and is used to contain any leakage from the primary piping and direct it to a leak detection and alarm system. The secondary piping may also provide the structures needed to support the primary piping, and standpipes for leak detection installation/maintenance and integrity testing. A view of a typical double-encased piping and leak detection system is shown below in Figure 1, copied from the *Double-Shell Tank Transfer Piping Subsystem Specification* (CHG 2000).

Figure 1. Double Encased Piping and Leak Detection



Double-encased piping was used in the Hanford tank piping distribution system for all new systems installed in the last 30 years except where the piping transits through concrete pits. In the case of pit transit, the concrete pits and covers provide secondary confinement and contain leak detection, eliminating the need for secondary encasement piping. Further details of transfer piping design specifications may be found in the *Double-Shell Tank Transfer Piping Subsystem Specification* (CHG 2000).

5.0 CALCULATION DETAILS

Detailed calculations are contained in Appendix A, Calculation Number RPP-LJJ-004. This section lists basic information regarding those calculations.

A representative double-encased pipe routing was modeled in the analysis using design characteristics from the project W-314 transfer lines. The W-314 design was used to estimate pipe guide spacing, pipe anchor spacing, and drain line size and configuration.

5.1 ASSUMPTIONS

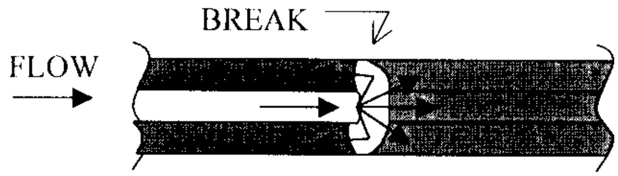
- Primary Pipe: 3-in. schedule 40, stainless steel
- Secondary Pipe: 6-in. schedule 40, carbon steel
- Drain Pipe in encasement: 1-in. and 2-in. schedule 40, carbon steel
- Primary pipe failure: guillotine break
- Maximum waste density is 1.5 kg/L
- Pump deadhead pressure is 650 psig at maximum waste density, with pump run-out at 285 gpm
- Encasement drains do not plug (based upon very high velocities through these lines)

5.2 MODELING OF THE PIPE BREAK

5.2.1 Pipeline Failure

The assumption of how the pipeline fails maximizes flow and secondary encasement pressure. Normal pipeline failure on straight piping sections, apart from external dropping or crushing scenarios, involves holes or slits in the metal wall from corrosion or weld failure. A large pressure drop occurs across this hole or slit opening minimizing the pressure buildup in any encasement. The primary pipe might shift because of the hydraulic forces at the break but a majority of the flow would still remain in the primary piping. The calculation in this report assumes a guillotine break that allows a transfer of the primary pipe contents into the primary and encasement pipeline. This is depicted below in Figure 2.

Figure 2. Liquid Flow After Guillotine Break



The percentage of flow distributed between the encasement and the downstream primary pipe is calculated based upon downstream pressure losses in both the primary and secondary pipe, and the pump response.

5.2.2 Immediate Encasement Fill-up

No effect for encasement fill-up was included in the calculation. For example, a 4000 foot encasement pipe section length would take approximately 20 minutes to fill before experiencing maximum pressure. During this time the transfer pump would most probably experience "run-out" – a condition where low-volume flow through the pump would cause cavitation and pressure fluctuations.

5.3 HYDRAULIC ANALYSIS

Standard hydraulic (pressure and flow) formulas were used, and solved with MathCad-2000®. Piping properties, and basic flow parameters/coefficients were taken from standard industrial and technical sources. Because of the non-standard geometry of the encasement flow obstructions (pipe guides, supports, and anchors) the pressure loss (k-resistance factors) from these flow obstructions was based upon the equivalent flow-area concept. This is a highly approximate method, and requires flow testing to obtain more accurate results. A low estimate of the k-resistance factors will result in an under prediction of the maximum pressure in the encasement piping.

Non-linear equations were then developed taking into account effects from drain discharge, supports within the encasement area, and pipe configuration. The calculations use an iterative process to balance flows, friction effects, and pressure losses to obtain steady-state pressure conditions.

6.0 CONCLUSIONS

The maximum expected internal pressure experienced by 6-in. encasement piping is well below the design pressure criteria values normally defined. At a minimum, pneumatic testing pressure limits may be reduced allowing safer inspection during construction. Design Authorities may employ the reduced pressure values to fabrication requirements.

It is recommended that future double-encased piping systems, of 4000 equivalent feet or less, employ one of two options for encasement pressure design criteria:

1. Design encasement to 240 psig for a system with a low point 1-inch diameter drain pipe, or 170 psig for a system with a low point 2-inch diameter drain pipe, or

2. Perform a specific case analysis with the same pipe pressure calculation methodology.

The recommended pressure values in #1 above assume a design pump shut-off head of 650 psig. These values may be linearly reduced with lower pump shut-off heads.

A significant reduction in the encasement design pressure can be obtained if both a high and low point drain are provided. Under this condition, and for an equivalent pipe section of 4000 feet, the minimum design encasement pressure could be limited to 140 psig with 1-inch diameter drains and 40 psig with 2-inch diameter drains.

7.0 ABBREVIATIONS

gpm	gallons per minute
in.	inch
kg/L	kilogram per liter
psig	pounds per square inch, gauge

8.0 REFERENCES

CHG, 2000, *Double-Shell Tank Transfer Piping Subsystem Specification*, HNF-4161, Rev. 0, Numatec Hanford Corporation for CH2M HILL Hanford Group, Inc., Richland, Washington.

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APPENDIX A.

DETAILED CALCULATION OF SECONDARY PIPING ENCASEMENT PRESSURE FROM PRIMARY PIPE FAILURE

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CH2MHILL Hanford Group, Inc.

EVALUATION ANALYSIS

Calc. No. RPP-LJJ-004
Revision: 0
Page No. 1 of 34

Client:	CH2M Hill Hanford Group, Inc.	WO/Job No.			
Subject:	Secondary Encasement Pipe Pressure Due to Primary Pipe Break in Waste Tank Transfer Piping System	Date:	09/07/2000	By:	L. J. Julyk
		Checked:	09/08/2000	By:	T. C. Oten
Location:	200 Area - Hanford Site, Richland, Washington	Revised:		By:	

PRESSURE IN SECONDARY ENCASEMENT PIPE DUE TO BREAK IN PRIMARY TRANSFER PIPE

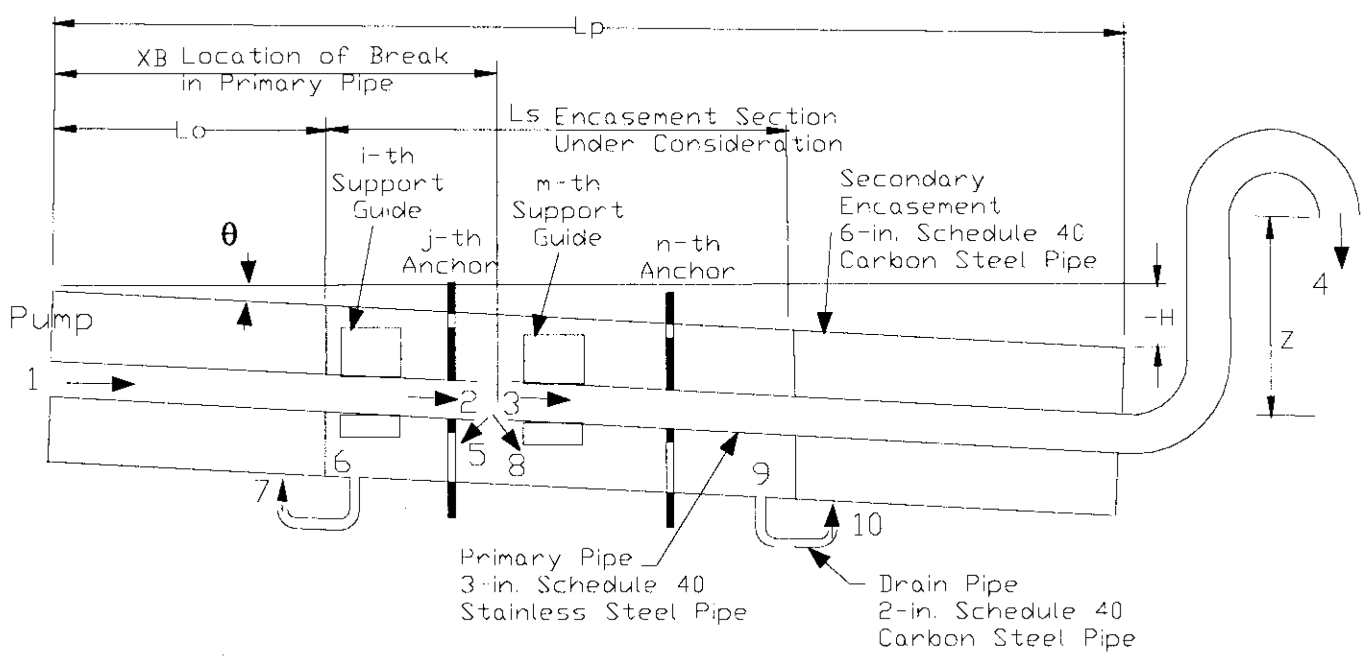
PROBLEM

Determine maximum pressure in secondary encasement pipe sections for postulated break in primary pipe during waste transfer operations within 200-East Area between double-shell tanks and proposed waste vitrification plant. Consider cases with only one drain at low point within the encasement section under consideration and with two drains (see Figure 1).

APPROACH

Basic pipeline hydraulic principles are applied to determine the maximum steady-state pressure in the secondary encasement pipe sections for a postulated break in the primary pipe during waste transfer operations. The resulting nonlinear system of equations that model the hydraulic conditions are solved using Mathcad 2000 Professional (Mathcad is a registered trademark of MathSoft, Inc. of Cambridge, Massachusetts). Head losses due to friction, exit losses at drains and at the pipe break are calculated. In addition, losses due to sudden contractions or enlargements from the primary pipe supports in the annulus region and changes in flow area from the annulus to drain pipe(s) are estimated using an equivalent hydraulic diameter approach to determine the K-resistance loss factors (see Blevins 1984). The conservation of mass (continuity) and energy (Bernoulli theorem) are applied between nodes (as numbered in Figure 1) and at the pipe break location plus a characteristic pump head relation is modeled to form the nonlinear system of equations that govern the steady-state flow resulting from a primary pipe break.

Figure 1. Transfer Pipe Layout Schematic.



The pressure in the primary pipe and encasement pipe with a break in the primary pipe are calculated through an iterative process. Initially the system flow rate is a constant as determined by the pump characteristics and system line losses. When the break occurs, the pump flow rate will increase depending on the location and size of the break. The increase in flow rate will cause both a pump head decrease and an increase in frictional line losses until a new equilibrium condition is reached.

ASSUMPTIONS

To bound the maximum pressure in the secondary encasement pipe sections the following conservative assumptions are applied:

1 Assume maximum waste bulk density during waste transfer of 1.5 kg/L (conservative, see Figure 6c).
2 Assume pump dead head pressure of 650 psig at maximum waste density and pump run-out flow rate of 285 gpm (see Figure 2).
3 Assume pipe roughness values of 50 mils due to general corrosion in carbon steel secondary encasement pipe and in drain pipe(s) and a pipe roughness value of 2 mils in the stainless steel primary pipe (conservative combination).
4 Assume a waste transfer temperature of 10 °C (conservative, see Figure 6b).
5 Assume a minimum pipe slope of 0.25% (typical specification limit for Hanford Site underground transfer piping).
6 Assume that pressure losses due to support guides and anchors can be approximated (first order approximation) from corresponding pressure losses due to long hole orifice plates with equivalent flow area.

SUMMARY RESULTS

Three cases for both a 1- and 2-in. drain line are considered. The resulting estimated maximum steady-state pressure in the secondary encasement pipe sections due to a postulated break in the primary pipe is summarized in Table 1. The predicted maximum steady-state pressure in the secondary encasement pipe as a function of primary pipe break location relative to the pump for various lengths of secondary encasement pipe sections between pits for each of the three cases are shown in Figures 6a, 7, and 8 for a 1-in. drain line and Figures 9, 10, and 11 for a 2-in. drain line. The encasement section under consideration is conservatively assumed to start at the pump (L_o = 0 ft). If the encasement section between pits is located some distance from the pump (L_o > 0 ft) then the maximum encasement pressure resulting from a primary pipe break within this section will decrease as L_o increases.

The effect of waste temperature on the encasement pressure due to a primary pipe break is shown in Figure 6b. The encasement pressure decreases with increasing waste temperature but the effect is negligible. A lower bound waste temperature of 10 °C is conservatively assumed throughout this analysis. The effect of waste bulk density is shown in Figure 6c. The encasement pressure increases with increasing waste bulk density. The effect of waste density is more significant than the effect of waste temperature. An upper bound waste bulk density of 1.5 kg/L is conservatively assumed throughout this analysis.

The worse case is obtained by conservatively assuming that the secondary encasement pipe section between pits is equal in length to the total primary pipe length. This is a very conservative assumption because there are typically a number of secondary encasement pipe sections in the total length of the transfer piping system. The maximum pressure depends on the location of the secondary encasement pipe section under consideration relative to the pump and the location of the break within that section as well as the length of the secondary encasement section.

The predicted maximum pressure in a secondary encasement pipe section decreases as the length of the section decreases and as the location of the encasement section increases relative to the pump. Note however that in the case of an upward sloping pipe with a low point drain (see Figures 7 and 10) the predicted pressures in the encasement pipe as a function of break location fall on a common curve for each encasement section length. An increase in the number of pipe supports and/or pipe anchors within the secondary encasement pipe section under consideration also increases the predicted maximum pressure. The spacing of support guides (9 ft) and anchors (110 ft) selected are average values based on pipe layout given in H-14-102663.

The area of greatest uncertainty in these results is in the prediction of the pressure drop associated with the support guides and anchors because of their unique geometry. A more accurate characterization of the pressure drop for these flow restrictions is best obtained through testing.

Table 1. Maximum Encasement Pressure (psig) Due to Waste Transfer Primary Pipe Break.

Case	Pipe Slope in Flow Direction	Primary Pipe Length (ft)	Length (ft) of Encasement Section Between Pits				Figure
			1,000	2,000	4,000	7,000	
1-in. Drain							
Two Drain	Up	7,000	130	134	140	147	6a
Low Point Drain	Up	7,000	223	223	223	223	7
Low Point Drain	Down	7,000	221	229	240	253	8
2-in. Drain							
Two Drain	Up	7,000	24	31	40	48	9
Low Point Drain	Up	7,000	78	88	89	89	10
Low Point Drain	Down	7,000	94	127	168	204	11

L_o = 0 ft, pipeline slope = 0.25%, waste temperature = 10 °C, and waste bulk density = 1.5 kg/L (see Figure 2 for assumed pump curve).

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H-14-102695, Piping Piping Pump Pits 241-AZ-01A&02A Modification Details, Revision 1.

Client:	CH2M Hill Hanford Group, Inc.	WO/Job No.	
Subject:	Secondary Encasement Pipe Pressure Due to Primary Pipe Break in Waste Tank Transfer Piping System	Date: 09/07/2000	By: L. J. Julyk
		Checked: 09/08/2000	By: T. C. Oten
Location:	200 Area - Hanford Site, Richland, Washington	Revised:	By:

ANALYSIS

$gpm := \frac{gal}{min}$ $\quad mil := \frac{in}{1000}$ $\quad cP := \frac{poise}{100}$ $\quad psi := 1 \cdot \frac{lbf}{in^2}$ units

$TOL = 1 \times 10^{-3}$

$CTOL = 1 \times 10^{-3}$

Waste Properties

$\boxed{\rho := 1.5 \cdot \frac{kg}{liter}}$ bulk density (input data)

The density and viscosity of water as a function of temperature (ºC) were obtained from Shook and Roco (1991) and Estey and Hu (1998) as

$$\rho_{water}(t_C) := \left[999.7 - 0.10512 \cdot (t_C - 10) - 0.005121 \cdot (t_C - 10)^2 + 0.00001329 \cdot (t_C - 10)^3\right] \cdot \frac{kg}{m^3}$$

mass density of water (5 ºC < t_C <100 ºC)

viscosity of water as a function of temperature (ºC)

$$\mu_{water}(t_C) := \begin{cases} 100 \cdot \exp\left[\ln(10) \cdot \left[\frac{1301}{998.333 + 8.1855 \cdot (t_C - 20) + 0.00585 \cdot (t_C - 20)^2} - 3.30233\right]\right] \cdot cP & \text{if } t_C \le 20 \\ (1.002) \cdot \exp\left[\ln(10) \cdot \left[\frac{\left[1.3272 \cdot (20 - t_C) - 0.001053 \cdot (t_C - 20)^2\right]}{t_C + 105}\right]\right] \cdot cP & \text{otherwise} \end{cases}$$

The above properties of water can be assumed for the pipeline flush condition as a function of the temperature of the flush water. These properties can vary if the flush water is treated.

The viscosity of the carrier liquid is given in Estey 2000 by the following relation:

ρ density of carrier liquid with dissolved solids

$x_{salt} := 0.9$ fraction of dissolved solids composed of sodium and other salts

$x_{caustic} := 0.1$ fraction of dissolved solids composed of sodium hydroxide

$$\mu(\rho, t_C) := \mu_{water}(t_C) \cdot \left[x_{salt} \cdot \left[1 + 1.071 \cdot \left(\frac{\rho}{\rho_{water}(t_C)} - 1\right)\right] + x_{caustic} \cdot \exp\left[\left[7.143 \cdot \left(\frac{\rho}{\rho_{water}(t_C)} - 1\right)\right]^{1.15}\right]\right]$$

The following temperature conversion functions are defined to convert between Fahrenheit and Celsius temperature scales.

$T_F(t_C) := \frac{9}{5} \cdot t_C + 32$ $\qquad T_C(t_F) := \frac{5}{9} \cdot (t_F - 32)$ $\qquad t_C := 10$ $\quad \mu(\rho, t_C) = 11.708\,cP$

$t_C := 60$ $\quad \mu(\rho, t_C) = 5.193\,cP$

CH2MHILL Hanford Group, Inc.
EVALUATION ANALYSIS

Calc. No. RPP-LJJ-004
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Client: CH2M Hill Hanford Group, Inc. WO/Job No.
Subject: Secondary Encasement Pipe Pressure Due to Primary Pipe Break in Waste Tank Transfer Piping System
Date: 09/07/2000 By: L. J. Julyk
Checked: 09/08/2000 By: T. C. Oten
Location: 200 Area - Hanford Site, Richland, Washington
Revised: By:

Pump Characteristics

Idealistic pump curve intended to bound the pressure and flow characteristics of all waste transfer pumps for farm-to-farm transfers as well as waste feed delivery to vitrification facility (RPP-5667)

$H_{ps} := 1440 \cdot ft$ pump shut off head

$Q_{p\_runout} := 285 \cdot gpm$ run-out flow rate

$H_1 := -0.29729 \cdot ft$ $H_2 := -0.01465 \cdot ft$ $H_3 := -5.61 \cdot 10^{-6} \cdot ft$

$H_{dh}(p_{dh}) := \dfrac{p_{dh}}{1.5 \cdot \dfrac{kg}{liter} \cdot g}$ adjusted dead head (input data) $p_{dh} := 650 \cdot psi$ at 1.5 kg/L

$H_{dh}(p_{dh}) = 1000\,ft$

$$H'_p(Q_p, p_{dh}) := \left[H_{ps} + H_1 \cdot \frac{Q_p}{gpm} + H_2 \cdot \left(\frac{Q_p}{gpm}\right)^2 + H_3 \cdot \left(\frac{Q_p}{gpm}\right)^3\right] \cdot \frac{H_{dh}(p_{dh})}{H_{ps}}$$ pump head characteristic curve

$$p_p(Q_p, \rho, p_{dh}) := H'_p(Q_p, p_{dh}) \cdot \rho \cdot g$$ pump discharge pressure

Figure 2a. Idealized Pump Head Curve.

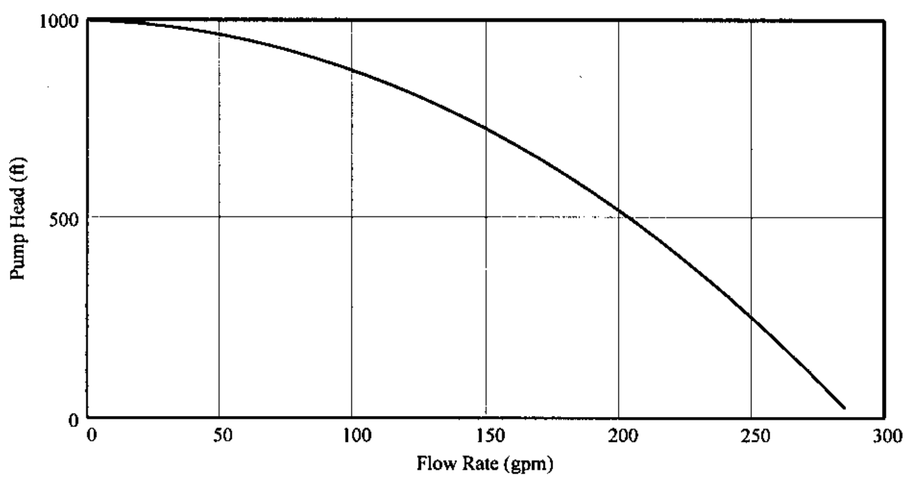
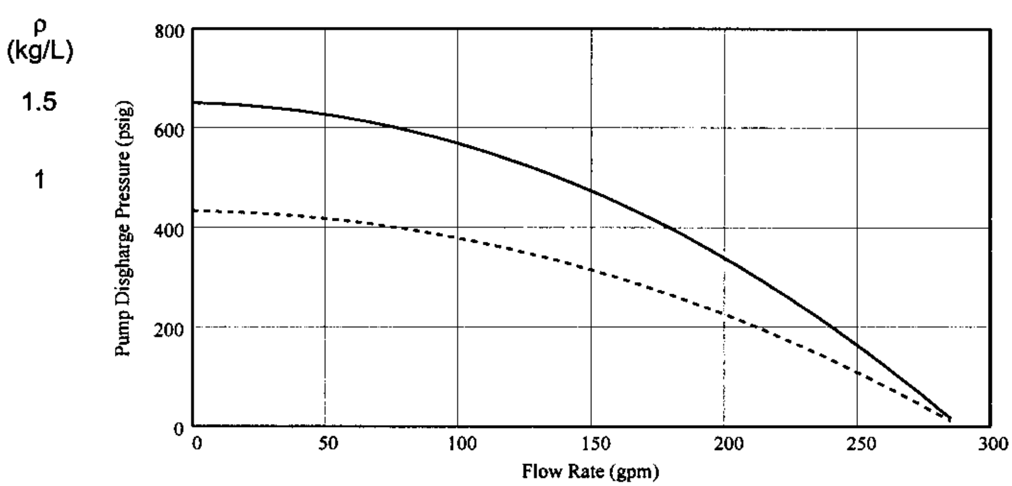


Figure 2b. Idealized Pump Discharge Pressure Curve.



Darcy Friction Factor

$R_e(D, v, \rho, \mu) := \frac{\rho}{\mu} \cdot D \cdot v$ Reynolds number

$\eta = \frac{\varepsilon}{D}$ relative roughness ratio

Olujic (1981) reports the following Darcy friction factor approximation developed by Churchill in 1977 that includes the laminar and turbulent regimes as well as the transition regime between laminar and turbulent flow

$$f(R_e, \eta) := \left| \begin{array}{l} A \leftarrow \left[2.457 \cdot \ln\left[\dfrac{1}{\left(\dfrac{7}{R_e}\right)^{0.9} + 0.27 \cdot \eta} \right] \right]^{16} \\ B \leftarrow \left(\dfrac{37530}{R_e} \right)^{16} \\ 8 \cdot \left[\left(\dfrac{8}{R_e} \right)^{12} + \left(\dfrac{1}{A + B} \right)^{\frac{3}{2}} \right]^{\frac{1}{12}} \end{array} \right.$$

primary pipe is stainless steel and secondary encasement is carbon steel

ε = pipe roughness, seamless steel pipe (Blevins 1984)
new condition ε = 0.8 to 4 mils (carbon or stainless steel)
light rust ε = 6 to 40 mils (carbon, 1/3 value for stainless)
general rust ε = 40 to 100 mils (carbon steel only)

Pipe Parameters

$A_f(D_i) := \frac{\pi}{4} \cdot D_i^2$ flow area of pipe

Primary transfer pipe, 3-in. schedule 40

$D_{Pi} := 3.068 \cdot in$ internal diameter)

$D_{Po} := 3.5 \cdot in$ outside diameter

$A_P := A_f(D_{Pi})$ $A_P = 7.393\, in^2$ flow area of pipe

Drain pipe

1-in. schedule 40	2-in. schedule 40	
$D_{D1i} := 1.049 \cdot in$	$D_{D2i} := 2.067 \cdot in$	nominal internal diameter
$A_{D1} := A_f(D_{D1i})$	$A_{D2} := A_f(D_{D2i})$	flow area of pipe
$A_{D1} = 0.864\, in^2$	$A_{D2} = 3.356\, in^2$	

Secondary encasement pipe annulus, 6-in. schedule 40

$D_{Si} := 6.065 \cdot in$ internal diameter

$A_S := \frac{\pi}{4} \cdot (D_{Si}^2 - D_{Po}^2)$ $A_S = 19.269\, in^2$ flow area of annulus region between primary and secondary pipe

$P_S := \pi \cdot (D_{Si} + D_{Po})$ $P_S = 30.049\, in$ wetted perimeter

$D_{H\_annulus} := 4 \cdot \frac{A_S}{P_S}$ $D_{H\_annulus} = 2.565\, in$ hydraulic diameter for secondary encasement pipe annulus

K-resistance Loss Factors

Head losses in the annulus region between the primary pipe and the secondary encasement due to steady-state flow in the annulus region resulting from a primary pipe break must be considered. Pipe bends are included in the effective length of the pipe section or pipe drain effective length. The head loss due to sudden contractions or enlargements from the primary pipe supports and changes in flow area from the annulus to drain pipe are estimated using an equivalent hydraulic diameter approach to determine the K-resistance loss factors (see Blevins 1984). That is, the head loss is given by $h_L = K\, V^2/2g$ where K (K-resistance loss factors) is estimated using an equivalent hydraulic diameter approach (see below) and V is the flow velocity in the annulus region of the pipe (upstream of the obstruction).

The primary transfer pipe is supported within the secondary encasement pipe at various locations along the pipeline by either pipe supports (Figure 3), pipe guides (Figure 4), or pipe anchors (Figure 5). The pipe supports typically occur at pipe bend locations. The pipe guides are typically spaced at 8 or 10 foot increments. The spacing of the pipe anchors is more variable, in the range from 10 to 20 times the spacing of the pipe guides (see H-14-102663). For simplicity, the head loss from a pipe support will be included for every 4th pipe guide to account for the pipe supports at pipe bends.

Figure 3. Encased Pipe Support. (H-14-102662)

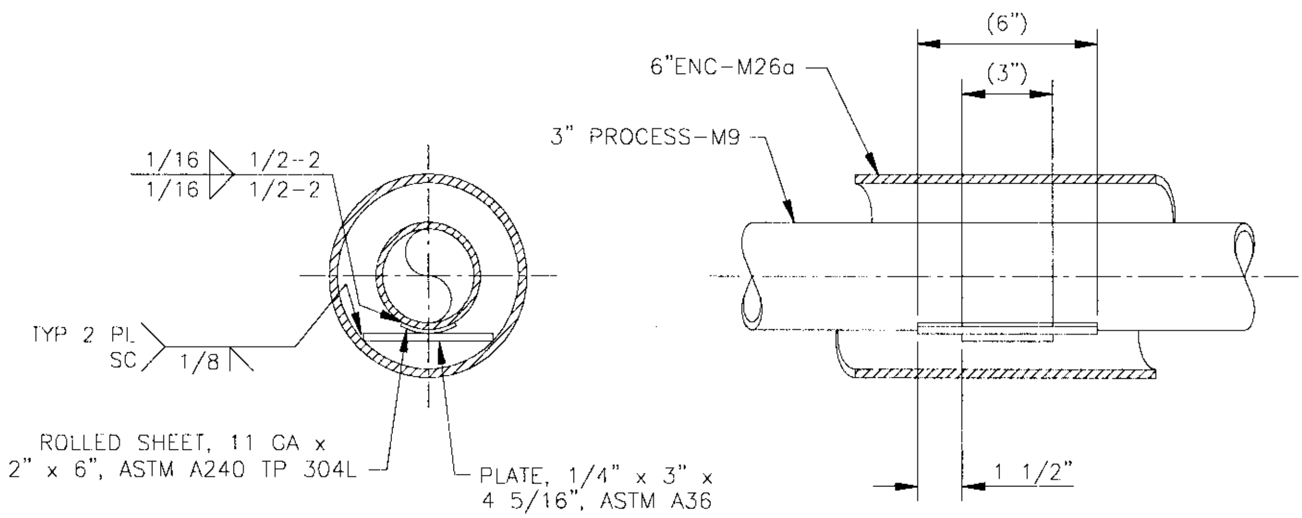


Figure 4. Encased Pipe Guide. (H-14-102662)

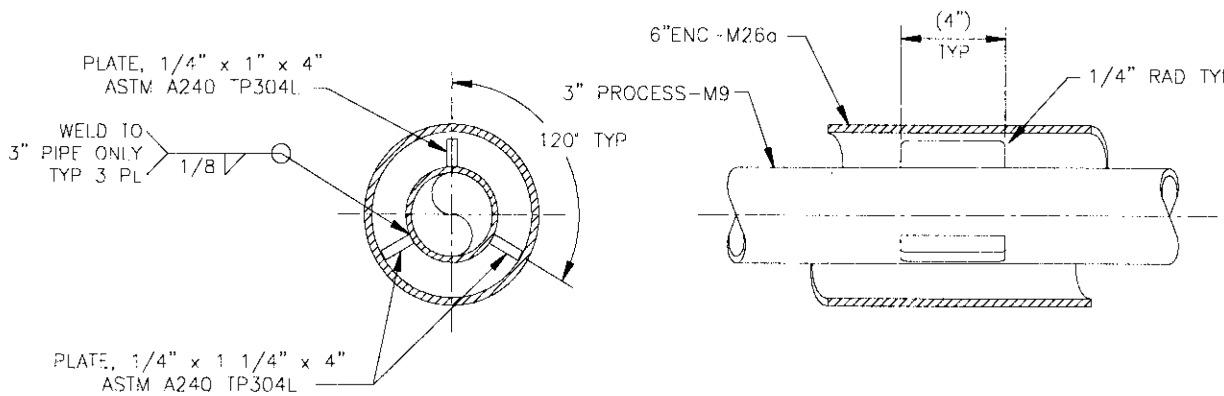


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Figure 5a. Encased Pipe Anchor. (H-14-102662)

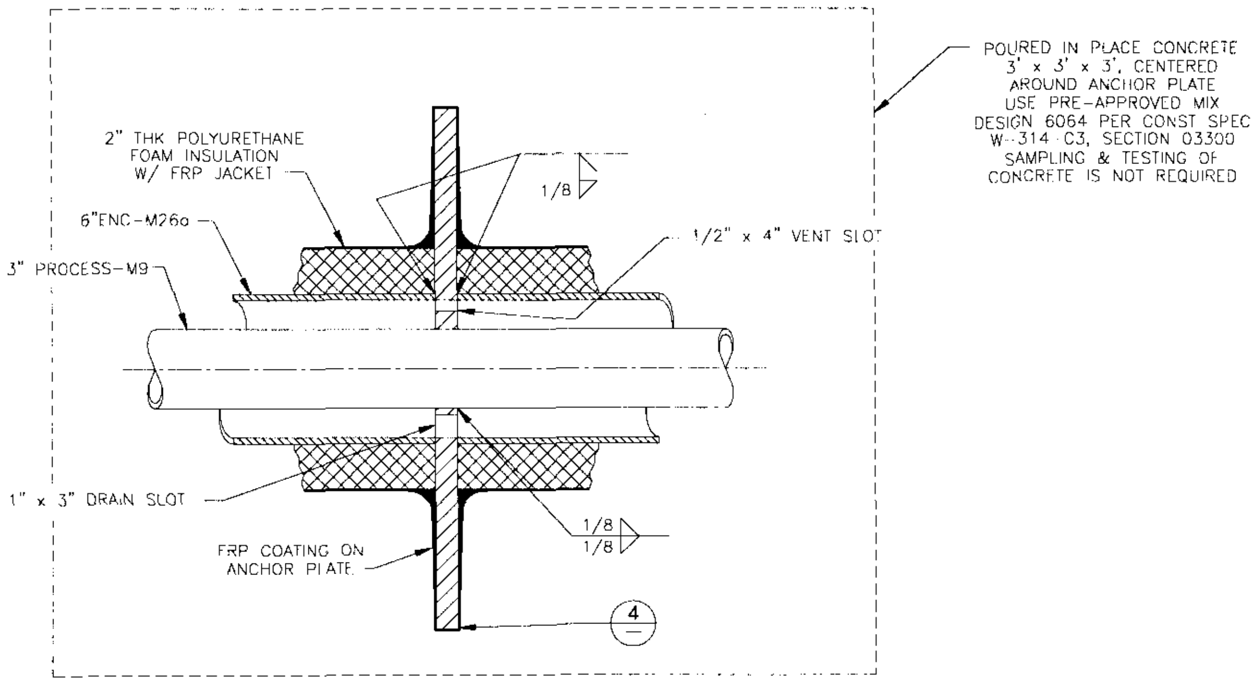
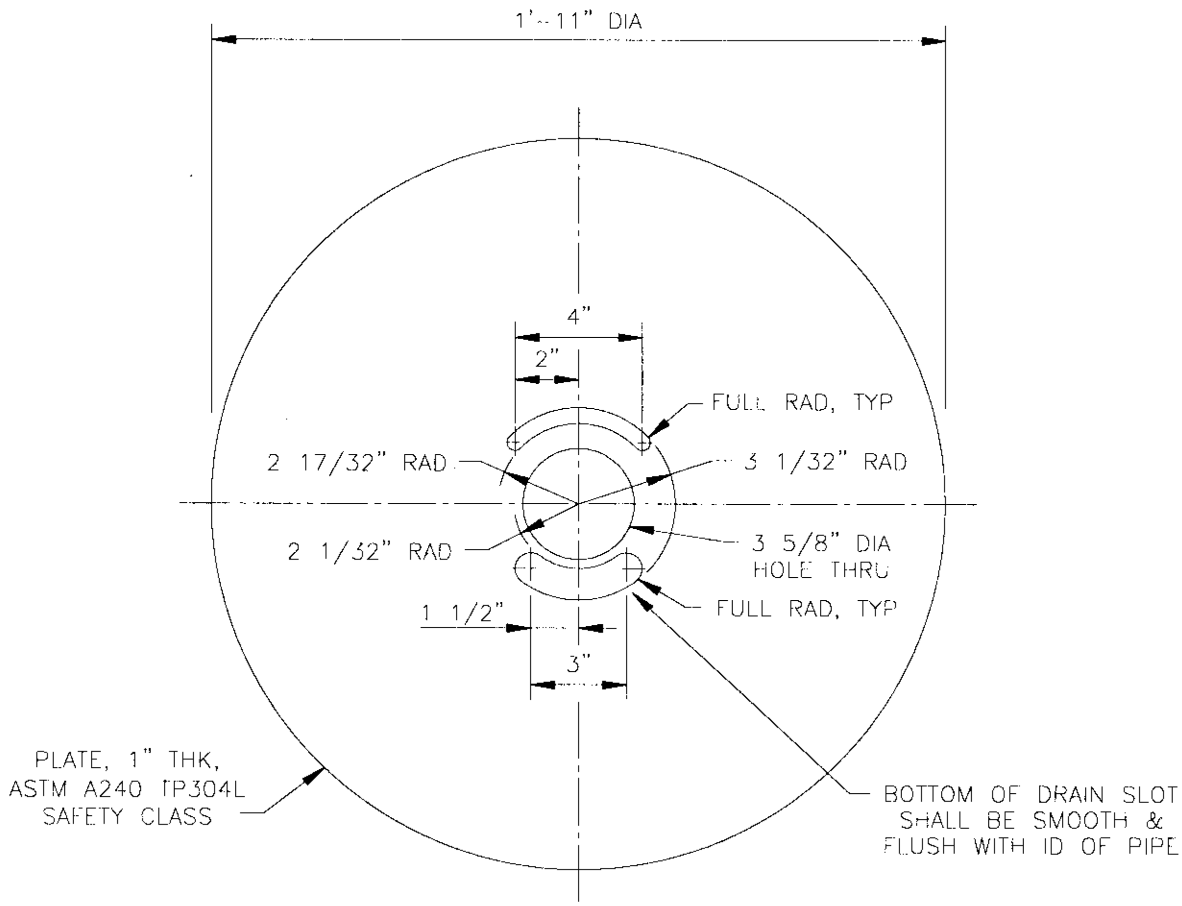


Figure 5b. Encased Pipe Anchor. (H-14-102662)



Assume that pressure losses due to supports, guides or anchors can be approximated (first order approximation) from corresponding pressure losses due to a long hole orifice plate with equivalent hydraulic flow area.

K-resistance loss factor for a long hole orifice plate with upstream and downstream flow diameter D, center hole of diameter D_o, and plate thickness L per Section 22, Eqn 4 of Lyons 1982 is applied to estimate the pressure loss from the pipe support, guide, and pipe anchor. The original equation is based on the flow velocity through the orifice and is recast herein in terms of the upstream flow velocity. First the correction factor accounting for plate thickness is given as

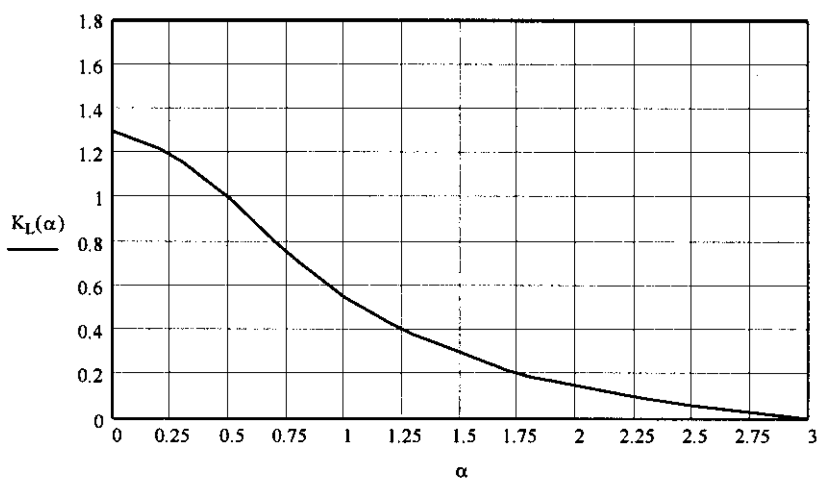
$i := 0..12$

Correction Factor K_L

$K_L(\alpha) := \text{linterp}(v\alpha, vK_L, \alpha)$

$v\alpha_i :=$	$vK_{L_i} :=$
0	1.3
0.25	1.2
0.5	1.0
0.75	0.75
1.0	0.55
1.25	0.4
1.5	0.3
1.75	0.2
2.0	0.15
2.25	0.1
2.5	0.06
2.75	0.03
3.0	0

Correction Factor K_L Based on $\alpha = L/D_o$ Ratio



Resulting K-resistance loss factor for a long hole orifice plate based on upstream flow velocity becomes

$$K(\beta,\alpha,Re,\eta) := \frac{1}{\beta^4}\cdot\left[0.5\cdot(1-\beta^2) + K_L(\alpha)\cdot\sqrt{1-\beta^2}\cdot(1-\beta^2) + (1-\beta^2)^2 + f(Re,\eta)\cdot\alpha\right]$$

Pipe support in annulus region (Figure 3) neglect effect of 11 GA x 2" x 6" rolled sheet

$t := \frac{1}{4}\cdot in$ support plate thickness

$A := A_S - \frac{1}{4}\cdot in\cdot\left(4+\frac{5}{16}\right)\cdot in$ $A = 18.191\, in^2$ flow area at pipe supports

$P := P_S + 2\cdot\left(4+\frac{5}{16}\right)\cdot in$ $P = 38.674\, in$ wetted perimeter

$D_{H\_support} := 4\cdot\frac{A}{P}$ $D_{H\_support} = 1.881\, in$ hydraulic diameter for pipe support guide

$\beta_{support} := \dfrac{D_{H\_support}}{D_{H\_annulus}}$ $\beta_{support} = 0.734$

$L_{support} := 3 \cdot in$ length of support

$\alpha_{support} := \dfrac{L_{support}}{D_{H\_support}}$ $\alpha_{support} = 1.595$ $K_L(\alpha_{support}) = 0.262$

$K_{support}(v,\rho,t_C,\varepsilon) := K\left(\beta_{support},\alpha_{support},\dfrac{R_e(D_{H\_annulus},v,\rho,\mu(\rho,t_C))}{\beta_{support}},\dfrac{\varepsilon}{D_{H\_support}}\right)$ $\rho = 1.5\dfrac{kg}{liter}$

$K_{support}\left(10\cdot\dfrac{ft}{sec},\rho,10,50\cdot mil\right) = 2.127$ Results for support at a flow velocity of 10 ft/s, liquid density of 1.5 kg/L, temperature of 10 °C, and pipe roughness of 50 mils.

Pipe support guide in annulus region (Figure 4)

$t := \dfrac{1}{4}\cdot in$ support plate thickness

$A := A_S - 3\cdot t\cdot\dfrac{(D_{Si} - D_{Po})}{2}$ $A = 18.307\,in^2$ flow area at pipe supports

$P := P_S - 6\cdot t + 6\cdot\dfrac{(D_{Si} - D_{Po})}{2}$ $P = 36.244\,in$ wetted perimeter

$D_{H\_guide} := 4\cdot\dfrac{A}{P}$ $D_{H\_guide} = 2.02\,in$ hydraulic diameter for pipe support guide

$\beta_{guide} := \dfrac{D_{H\_guide}}{D_{H\_annulus}}$ $\beta_{guide} = 0.788$

$L_{guide} := 4\cdot in$ length of guide

$\alpha_{guide} := \dfrac{L_{guide}}{D_{H\_guide}}$ $\alpha_{guide} = 1.98$ $K_L(\alpha_{guide}) = 0.154$

$K'_{guide}(v,\rho,t_C,\varepsilon) := K\left(\beta_{guide},\alpha_{guide},\dfrac{R_e(D_{H\_annulus},v,\rho,\mu(\rho,t_C))}{\beta_{guide}},\dfrac{\varepsilon}{D_{H\_guide}}\right)$

$K'_{guide}\left(10\cdot\dfrac{ft}{sec},\rho,10,50\cdot mil\right) = 1.24$ Results for support guide at a flow velocity of 10 ft/s, liquid density of 1.5 kg/L, temperature of 10 °C, and pipe roughness of 50 mils.

For simplicity, combining the pipe support resistance with every 4th guide, the effective K-resistance for the guide becomes

$K_{guide}(v,\rho,t_C,\varepsilon) := K'_{guide}(v,\rho,t_C,\varepsilon) + \dfrac{1}{4}\cdot K_{support}(v,\rho,t_C,\varepsilon)$ $K_{guide}\left(10\cdot\dfrac{ft}{sec},\rho,10,50\cdot mil\right) = 1.772$

Pipe anchor in annulus region (Figure 5)

$r_1 := \left(2 + \frac{17}{32}\right) \cdot in$ $\qquad t_1 := \frac{D_{Si}}{2} - r_1$ $\qquad L_1 := 4 \cdot in$ $\qquad \theta_1 := 2 \cdot asin\left[\frac{L_1}{\left(\frac{D_{Si}}{2} + r_1\right)}\right]$

$r_1 = 2.531\, in$ $\qquad t_1 = 0.501\, in$ $\qquad \theta_1 = 91.934\, deg$

$r_2 := \left(2 + \frac{1}{32}\right) \cdot in$ $\qquad t_2 := \frac{D_{Si}}{2} - r_2$ $\qquad L_2 := 3 \cdot in$ $\qquad \theta_2 := 2 \cdot asin\left[\frac{L_2}{\left(\frac{D_{Si}}{2} + r_2\right)}\right]$

$r_2 = 2.031\, in$ $\qquad t_2 = 1.001\, in$ $\qquad \theta_2 = 72.662\, deg$

$$A := \frac{\pi}{4} \cdot t_1^2 + \frac{\theta_1}{2} \cdot \left[\left(\frac{D_{Si}}{2}\right)^2 - r_1^2\right] + \frac{\pi}{4} \cdot t_2^2 + \frac{\theta_2}{2} \cdot \left[\left(\frac{D_{Si}}{2}\right)^2 - r_2^2\right]$$

$A = 6.437\, in^2$ flow area of pipe

$$P := \pi \cdot t_1 + \theta_1 \cdot \left(\frac{D_{Si}}{2} + r_1\right) + \pi \cdot t_2 + \theta_2 \cdot \left(\frac{D_{Si}}{2} + r_2\right)$$

$P = 20.069\, in$ wetted perimeter

$D_{H\_anchor} := 4 \cdot \frac{A}{P}$ $\qquad D_{H\_anchor} = 1.283\, in$ hydraulic diameter for anchor

$\beta_{anchor} := \frac{D_{H\_anchor}}{D_{H\_annulus}}$ $\qquad \beta_{anchor} = 0.5$ $\qquad L_{anchor} := 1 \cdot in$ $\qquad \alpha_{anchor} := \frac{L_{anchor}}{D_{H\_anchor}}$ $\qquad \alpha_{anchor} = 0.779$ $\qquad K_L(\alpha_{anchor}) = 0.726$

$$K_{anchor}(v, \rho, t_C, \varepsilon) := K\left(\beta_{anchor}, \alpha_{anchor}, \frac{R_e(D_{H\_annulus}, v, \rho, \mu(\rho, t_C))}{\beta_{anchor}}, \frac{\varepsilon}{D_{H\_anchor}}\right)$$

$K_{anchor}\left(10 \cdot \frac{ft}{sec}, \rho, 10, 50 \cdot mil\right) = 23.32$ Results for anchor at a flow velocity of 10 ft/s, liquid density of 1.5 kg/L, temperature of 10 °C, and pipe roughness of 50 mils.

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Revised: By:

Abrupt contraction from annulus region to drain pipe (Blevins 1984, Case 11 of Table 6-7 rewritten in terms of upstream flow velocity, see also CRANE 1988, Eqn 2-11)

	1-in. drain	2-in. drain
$\beta_D(D_{Di}) := \dfrac{D_{Di}}{D_{H\_annulus}}$	$\beta_D(D_{D1i}) = 0.409$	$\beta_D(D_{D2i}) = 0.806$
$K_D(D_{Di}) := \dfrac{1}{2} \cdot \left(1 - \beta_D(D_{Di})^2\right) \cdot \dfrac{1}{\beta_D(D_{Di})^4}$	$K_D(D_{D1i}) = 14.884$	$K_D(D_{D2i}) = 0.416$

Exit to atmosphere at drain (sudden enlargement, CRANE 1988, Eqn 2-9.1)

$K_E(\beta) := \left(1 - \beta^2\right)^2$ $\quad \beta := 0$ $\quad K_E := K_E(\beta)$ $\quad K_E = 1$

Loss at break (RPP-5667, 2000)

Contraction coefficient for square edge orifice $C_v := 0.82$ and the velocity resistance K_v is given by

$K_v(C_v) := C_v^{-2} - 1$ $\quad K_B := K_v(C_v)$ $\quad K_B = 0.487$

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Input Parameter Data

up stream of break	down stream of break	
$L_i := 9 \cdot ft$	$L_m := L_i$	spacing of primary pipe guides
$\lambda := 12$		spacing parameter for anchors
$L_j := \lambda \cdot L_i$	$L_n := L_j$	spacing of primary pipe anchors
$L_j = 108\,ft$		

$L_D(D_{Di}) := 3 \cdot ft + 3 \cdot 30 \cdot D_{Di}$ approximate equivalent length of drain pipe including three standard 90° elbows (L/D=30)

D_{Di} internal pipe diameter of drain $L_D(D_{D1i}) = 10.9\,ft$ $L_D(D_{D2i}) = 18.5\,ft$

F_{D6} F_{D9} switch to block (= 0) or open (= 1) drain location 6 or 9, respectively

$\Delta Z_D := -1 \cdot ft$ approximate change in elevation at drain

$L_P := 7000 \cdot ft$ total equivalent length of primary pipe from pump to discharge exit

$Z := 25 \cdot ft$ vertical increase in elevation at end of primary pipe at discharge to tank at WTP

$H := 0.25\% \cdot L_P$ change in elevation of primary pipe from pump to point just before vertical increase in elevation at end of primary pipe at discharge to tank (see Figure 1)

$H = 17.5\,ft$

$L_o := 1000 \cdot ft$ start distance from pump of secondary encasement section under consideration

$L_S := 4000 \cdot ft$ length of secondary encasement section under consideration between drains

$x_B := 200 \cdot ft + L_o$ distance of break in primary pipe from pump

t_C temperature of waste (°C)

ρ bulk density of waste (kg/L)

Determination of number of upstream and downstream support guides and anchors relative to break location for encasement section under consideration. Sample results given below are for above specified parameters. Actual values are calculated during solution as appropriate.

$$J(L_i, L_o, x_B) := \left| \begin{array}{l} n \leftarrow \text{round}\left(\dfrac{x_B - L_o}{\lambda \cdot L_i}\right) \\ 0 \text{ if } n \le 0 \\ n \text{ otherwise} \end{array} \right.$$

number of <u>anchors</u> within secondary encasement section under consideration <u>before</u> break

$J(L_i, L_o, x_B) = 2$

$$I(L_i, L_o, x_B) := \left| \begin{array}{l} n \leftarrow \text{round}\left(\dfrac{x_B - L_o}{L_i} - J(L_i, L_o, x_B)\right) \\ 0 \ \text{if} \ n \le 0 \\ n \ \text{otherwise} \end{array} \right.$$

number of support guides within secondary encasement section under consideration before break

$I(L_i, L_o, x_B) = 20$

$$N(L_i, L_o, L_S, x_B) := \left| \begin{array}{l} n \leftarrow \text{round}\left[\dfrac{L_S - (x_B - L_o)}{\lambda \cdot L_i}\right] \\ 0 \ \text{if} \ n \le 0 \\ n \ \text{otherwise} \end{array} \right.$$

number of anchors within secondary encasement section under consideration after break

$N(L_i, L_o, L_S, x_B) = 35$

$$M(L_i, L_o, L_S, x_B) := \left| \begin{array}{l} n \leftarrow \text{round}\left[\dfrac{L_S - (x_B - L_o)}{L_i} - N(L_i, L_o, L_S, x_B)\right] \\ 0 \ \text{if} \ n \le 0 \\ n \ \text{otherwise} \end{array} \right.$$

number of support guides within secondary encasement section under consideration after break

$M(L_i, L_o, L_S, x_B) = 387$

$g = 32.174\ \text{ft}\,\text{sec}^{-2}$

$V_z := 0 \cdot \text{ft} \cdot \text{sec}^{-1}$

Apply conservation of mass (continuity) and energy (Bernoulli theorem) between nodes (see Figure 1) and at the pipe break plus the characteristic pump head relation (see Figure 2) to model the nonlinear system of equations that govern the steady-state flow behavior resulting from a primary pipe break at location x_B relative to pump.

$D_{Di} := D_{D1i}$

Initial guesses $Q := 245 \cdot \text{gpm}$ $V_1 := \dfrac{Q}{A_P}$ $V_1 = 10.633\,\dfrac{\text{ft}}{\text{sec}}$ flow velocities

$F_{D6} := 1$

$H_P := H'_p(Q, p_{dh})$ pump head

$F_{D9} := 1$

$V_5 := \dfrac{V_1}{6}$

$p_2 := 100 \cdot \text{psi}$ primary pipe pressure just up stream of break

$p_3 := 100 \cdot \text{psi}$ primary pipe pressure just down stream of break

$V_6 := V_5 \cdot \dfrac{A_S}{A_f(D_{Di})}$

$\dfrac{A_S}{A_P} = 2.607$

$p_5 := 100 \cdot \text{psi}$ secondary pipe pressure just up stream of break

$p_6 := 50 \cdot \text{psi}$ secondary pipe pressure at drain up stream of break

$V_8 := \dfrac{V_1}{6}$

$\dfrac{A_S}{A_f(D_{Di})} = 22.296$

$p_8 := 100 \cdot \text{psi}$ secondary pipe pressure just down stream of break

$p_9 := 50 \cdot \text{psi}$ secondary pipe pressure at drain down stream of break

$V_9 := V_8 \cdot \dfrac{A_S}{A_f(D_{Di})}$

apply conservation of mass (continuity) at break $V_3 := V_1 - \dfrac{A_S}{A_P} \cdot (V_5 + V_8)$ $V_3 = 1.395\,\dfrac{\text{ft}}{\text{sec}}$

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Nonlinear governing system of equations

Given apply conservation of mass (continuity) and energy (Bernoulli theorem)

$V_1 \ge V_z \quad V_3 \ge V_z \quad V_5 \ge V_z \quad V_6 \ge V_z \quad V_8 \ge V_z \quad V_9 \ge V_z$

$A_S \cdot V_5 = F_{D6} \cdot A_f(D_{Di}) \cdot V_6 \qquad A_S \cdot V_8 = F_{D9} \cdot A_f(D_{Di}) \cdot V_9 \qquad A_P \cdot V_3 = \left[A_P \cdot V_1 - (A_S \cdot V_5 + A_S \cdot V_8)\right]$ continuity

$H_P = H'_p(A_P \cdot V_1, p_{dh})$ pump head curve

Bernoulli (between nodes, see Figure 1)

$$\left(\frac{V_1^2}{2 \cdot g} + H_P - f\left(R_e(D_{Pi}, V_1, \rho, \mu(\rho, t_C)), \frac{\varepsilon_P}{D_{Pi}}\right) \cdot \frac{x_B}{D_{Pi}} \cdot \frac{V_1^2}{2 \cdot g}\right) = \left(\frac{p_2}{\rho \cdot g} + \frac{V_1^2}{2 \cdot g} + x_B \cdot \frac{H}{L_P}\right) \quad \text{1-2}$$

$$\left(\frac{p_2}{\rho \cdot g} + \frac{V_1^2}{2 \cdot g}\right) = \left(\frac{p_3}{\rho \cdot g} + \frac{V_3^2}{2 \cdot g}\right) \quad \text{2-3}$$

$$\left(\frac{p_3}{\rho \cdot g} + \frac{V_3^2}{2 \cdot g} + x_B \cdot \frac{H}{L_P} - f\left(R_e(D_{Pi}, V_3, \rho, \mu(\rho, t_C)), \frac{\varepsilon_P}{D_{Pi}}\right) \cdot \frac{L_P - x_B}{D_{Pi}} \cdot \frac{V_3^2}{2 \cdot g} - K_E \cdot \frac{V_3^2}{2 \cdot g}\right) = \left(\frac{V_3^2}{2 \cdot g} + L_P \cdot \frac{H}{L_P} + Z\right) \quad \text{3-4}$$

$$\left(\frac{p_2}{\rho \cdot g} + \frac{V_1^2}{2 \cdot g} - K_B \cdot \frac{V_5^2}{2 \cdot g}\right) = \left(\frac{p_5}{\rho \cdot g} + \frac{V_5^2}{2 \cdot g}\right) \quad \text{2-5}$$

$$\left(\begin{aligned}&\frac{p_5}{\rho \cdot g} + \frac{V_5^2}{2 \cdot g} + x_B \cdot \frac{H}{L_P} - f\left(R_e(D_{H\_annulus}, V_5, \rho, \mu(\rho, t_C)), \frac{\varepsilon_S}{D_{H\_annulus}}\right) \cdot \frac{x_B - L_o}{D_{H\_annulus}} \cdot \frac{V_5^2}{2 \cdot g} \ldots \\ &+ -I(L_i, L_o, x_B) \cdot K_{guide}(V_5, \rho, t_C, \varepsilon_S) \cdot \frac{V_5^2}{2 \cdot g} - J(L_i, L_o, x_B) \cdot K_{anchor}(V_5, \rho, t_C, \varepsilon_S) \cdot \frac{V_5^2}{2 \cdot g} - K_D(D_{Di}) \cdot \frac{V_5^2}{2 \cdot g}\end{aligned}\right) = \left(\begin{aligned}&\frac{p_6}{\rho \cdot g} + \frac{V_6^2}{2 \cdot g} \ldots \\ &+ L_o \cdot \frac{H}{L_P}\end{aligned}\right) \quad \text{5-6}$$

$$\left(\frac{p_6}{\rho \cdot g} + \frac{V_6^2}{2 \cdot g} - f\left(R_e(D_{Di}, V_6, \rho, \mu(\rho, t_C)), \frac{\varepsilon_D}{D_{Di}}\right) \cdot \frac{L_D(D_{Di})}{D_{Di}} \cdot \frac{V_6^2}{2 \cdot g} - K_E \cdot \frac{V_6^2}{2 \cdot g}\right) = \frac{V_6^2}{2 \cdot g} + \Delta Z_D \quad \text{6-7}$$

$$\left(\frac{p_2}{\rho \cdot g} + \frac{V_1^2}{2 \cdot g} - K_B \cdot \frac{V_8^2}{2 \cdot g}\right) = \left(\frac{p_8}{\rho \cdot g} + \frac{V_8^2}{2 \cdot g}\right) \quad \text{2-8}$$

$$\left[\begin{aligned}&\frac{p_8}{\rho \cdot g} + \frac{V_8^2}{2 \cdot g} + x_B \cdot \frac{H}{L_P} - f\left(R_e(D_{H\_annulus}, V_8, \rho, \mu(\rho, t_C)), \frac{\varepsilon_S}{D_{H\_annulus}}\right) \cdot \frac{L_S - (x_B - L_o)}{D_{H\_annulus}} \cdot \frac{V_8^2}{2 \cdot g} \ldots \\ &+ -M(L_i, L_o, L_S, x_B) \cdot K_{guide}(V_8, \rho, t_C, \varepsilon_S) \cdot \frac{V_8^2}{2 \cdot g} \ldots \\ &+ -N(L_i, L_o, L_S, x_B) \cdot K_{anchor}(V_8, \rho, t_C, \varepsilon_S) \cdot \frac{V_8^2}{2 \cdot g} - K_D(D_{Di}) \cdot \frac{V_8^2}{2 \cdot g}\end{aligned}\right] = \left[\begin{aligned}&\frac{p_9}{\rho \cdot g} + \frac{V_9^2}{2 \cdot g} \ldots \\ &+ (L_S + L_o) \cdot \frac{H}{L_P}\end{aligned}\right] \quad \text{8-9}$$

$$\left(\frac{p_9}{\rho \cdot g} + \frac{V_9^2}{2 \cdot g} - f\left(R_e(D_{Di}, V_9, \rho, \mu(\rho, t_C)), \frac{\varepsilon_D}{D_{Di}}\right) \cdot \frac{L_D(D_{Di})}{D_{Di}} \cdot \frac{V_9^2}{2 \cdot g} - K_E \cdot \frac{V_9^2}{2 \cdot g}\right) = \frac{V_9^2}{2 \cdot g} + \Delta Z_D \quad \text{9-10}$$

Solution function

$$ff(L_o,L_S,x_B,\rho,t_C,p_{dh},\varepsilon_P,\varepsilon_S,\varepsilon_D,D_{Di},F_{D6},F_{D9},\Delta Z_D,L_P,H,Z) := \text{Find}(H_P,p_2,p_3,p_5,p_6,p_8,p_9,V_1,V_3,V_5,V_6,V_8,V_9)$$

For plotting, following function returns nth solution variable at points defined in vector x_B n = result variable selected

$$PP(L_o,L_S,x_B,\rho,t_C,p_{dh},\varepsilon_P,\varepsilon_S,\varepsilon_D,D_{Di},F_{D6},F_{D9},\Delta Z_D,L_P,H,Z,n) :=$$

```
vp ← 0
for i ∈ 0.. length(x_B) − 1
    x_BB ← x_B_i
    p ← 0
    p ← ff(L_o,L_S,x_BB,ρ,t_C,p_dh,ε_P,ε_S,ε_D,D_Di,F_D6,F_D9,ΔZ_D,L_P,
    vp_i ← p_n,0
vp
```

CH2MHILL Hanford Group, Inc.
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Client: CH2M Hill Hanford Group, Inc.
Subject: Secondary Encasement Pipe Pressure Due to Primary Pipe Break in Waste Tank Transfer Piping System
Location: 200 Area - Hanford Site, Richland, Washington

WO/Job No. ______
Date: 09/07/2000 By: L. J. Julyk
Checked: 09/08/2000 By: T. C. Oten
Revised: ______ By: ______

Two Drain Case - 1-in. Drain

$n := 3$

Input=======Maximum Pressure====================

$L_o := 0 \cdot ft$ $\quad p_{dh} := 650 \cdot psi$ $\quad H = 17.5\,ft$ $\quad \varepsilon_P := 2 \cdot mil$

$L_S := 4000 \cdot ft$ $\quad \rho := 1.5 \cdot \frac{kg}{liter}$ $\quad Z := 25 \cdot ft$ $\quad \varepsilon_S := 50 \cdot mil$

$L_P := 7000 \cdot ft$ $\quad F_{D6} := 1$ $\quad \varepsilon_D := 50 \cdot mil$

$x_B := 0 \cdot ft + L_o$ $\quad t_C := 10\,°C$ $\quad F_{D9} := 1$ $\quad D_{Di} := D_{D1i}$ $\quad \Delta Z_D = -1\,ft$ $\quad L_D(D_{Di}) = 10.867\,ft$

$$\begin{pmatrix} h_P \\ P_2 \\ P_3 \\ P_5 \\ P_6 \\ P_8 \\ P_9 \\ v_1 \\ v_3 \\ v_5 \\ v_6 \\ v_8 \\ v_9 \end{pmatrix} := ff(L_o, L_S, x_B, \rho, t_C, p_{dh}, \varepsilon_P, \varepsilon_S, \varepsilon_D, D_{Di}, F_{D6}, F_{D9}, \Delta Z_D, L_P, H, Z)$$

Results---

$h_P = 213.4\,ft$ $\quad H'_p(A_P \cdot v_1, p_{dh}) = 213.4\,ft$ $\quad \mu_t := \mu(\rho, t_C)$ $\quad \mu_t = 11.708\,cP$ $\quad L_i = 9\,ft$ $\quad L_j = 108\,ft$ $\quad D_{Di} = 1.049\,in$

$P_2 = 138.8\,psi$ $\quad v_1 = 11.1\,ft\,sec^{-1}$ $\quad A_P \cdot v_1 = 256.3\,gpm$ $\quad \frac{\varepsilon_P}{D_{Pi}} = 0.00065$ $\quad \frac{\varepsilon_S}{D_{H\_annulus}} = 0.01949$ $\quad \frac{\varepsilon_D}{D_{Di}} = 0.04766$

$P_3 = 139.9\,psi$ $\quad v_3 = 3.6\,ft\,sec^{-1}$ $\quad A_P \cdot v_3 = 82.7\,gpm$

$P_5 = 140\,psi$ $\quad v_5 = 1.6\,ft\,sec^{-1}$ $\quad A_S \cdot v_5 = 96.4\,gpm$

$P_6 = 126.7\,psi$ $\quad v_6 = 35.8\,ft\,sec^{-1}$ $\quad F_{D6} \cdot A_f(D_{Di}) \cdot v_6 = 96.4\,gpm$

$P_8 = 140\,psi$ $\quad v_8 = 1.3\,ft\,sec^{-1}$ $\quad A_S \cdot v_8 = 77.1\,gpm$

$P_9 = 81\,psi$ $\quad v_9 = 28.6\,ft\,sec^{-1}$ $\quad F_{D9} \cdot A_f(D_{Di}) \cdot v_9 = 77.1\,gpm$

$$v_1 \cdot A_P = A_P \cdot v_3 + A_S \cdot v_5 + A_S \cdot v_8 = 256.3\,gpm$$

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Client: CH2M Hill Hanford Group, Inc.
Subject: Secondary Encasement Pipe Pressure Due to Primary Pipe Break in Waste Tank Transfer Piping System
Location: 200 Area - Hanford Site, Richland, Washington

WO/Job No. ______
Date: 09/07/2000 By: L. J. Julyk
Checked: 09/08/2000 By: T. C. Oten
Revised: ______ By: ______

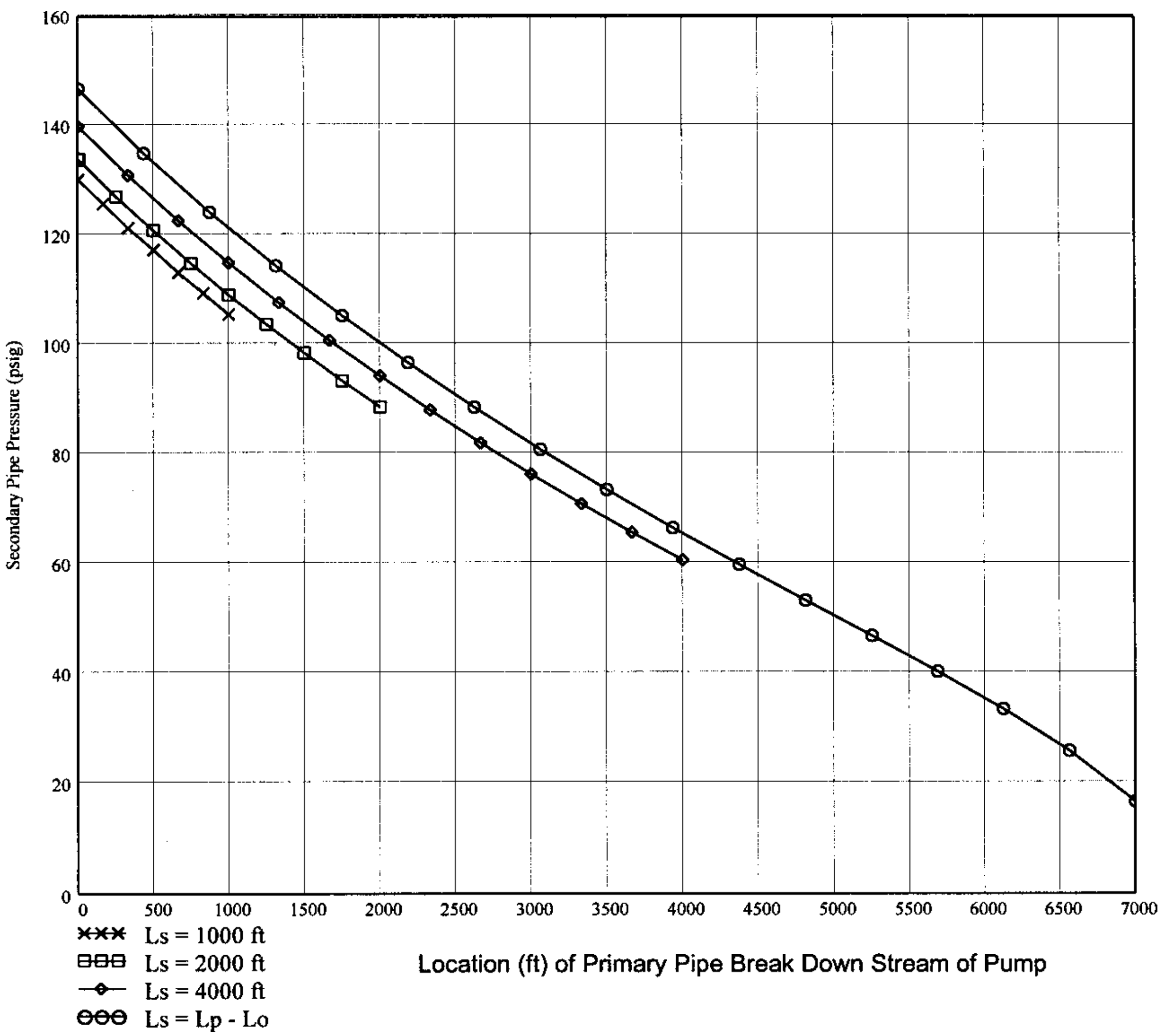
Figure 6a. Maximum Pressure in Secondary Encasement Pipe Due to Primary Pipe Break within Encasement Section with Two 1-in. Drains in Encasement Section of Length L_s

Starting at L_o = 0 ft Relative to Pump and for a Waste Temperature of 10 °C.

$Z = 25\,\text{ft}$ $p_{dh} = 650\,\text{psi}$ $\rho = 1.5\,\frac{\text{kg}}{\text{liter}}$ $\mu(\rho, t_C) = 11.708\,\text{cP}$ $\varepsilon_P = 2\,\text{mil}$ $\varepsilon_S = 50\,\text{mil}$ $\varepsilon_D = 50\,\text{mil}$ $F_{D6} = 1$

$H = 17.5\,\text{ft}$ $t_C = 10\ ^\circ\text{C}$ $L_o = 0\,\text{ft}$ $L_P = 7000\,\text{ft}$ $L_i = 9\,\text{ft}$ $L_j = 108\,\text{ft}$ $D_{Di} = 1.049\,\text{in}$ $F_{D9} = 1$

$\Delta Z_D = -1\,\text{ft}$ $L_D(D_{Di}) = 10.9\,\text{ft}$



Effect of Waste Temperature

$TT(L_o, L_S, x_B, \rho, t_C, p_{dh}, \varepsilon_P, \varepsilon_S, \varepsilon_D, D_{Di}, F_{D6}, F_{D9}, \Delta Z_D, L_P, H, Z, n) :=$

$vp \leftarrow 0$
for $i \in 0..\text{length}(t_C) - 1$
  $t_{CC} \leftarrow t_{C_i}$
  $p \leftarrow 0$
  $p \leftarrow ff(L_o, L_S, x_B, \rho, t_{CC}, p_{dh}, \varepsilon_P, \varepsilon_S, \varepsilon_D, D_{Di}, F_{D6}, F_{D9}, \Delta Z_D, L_P,$
  $vp_i \leftarrow p_{n,0}$
vp

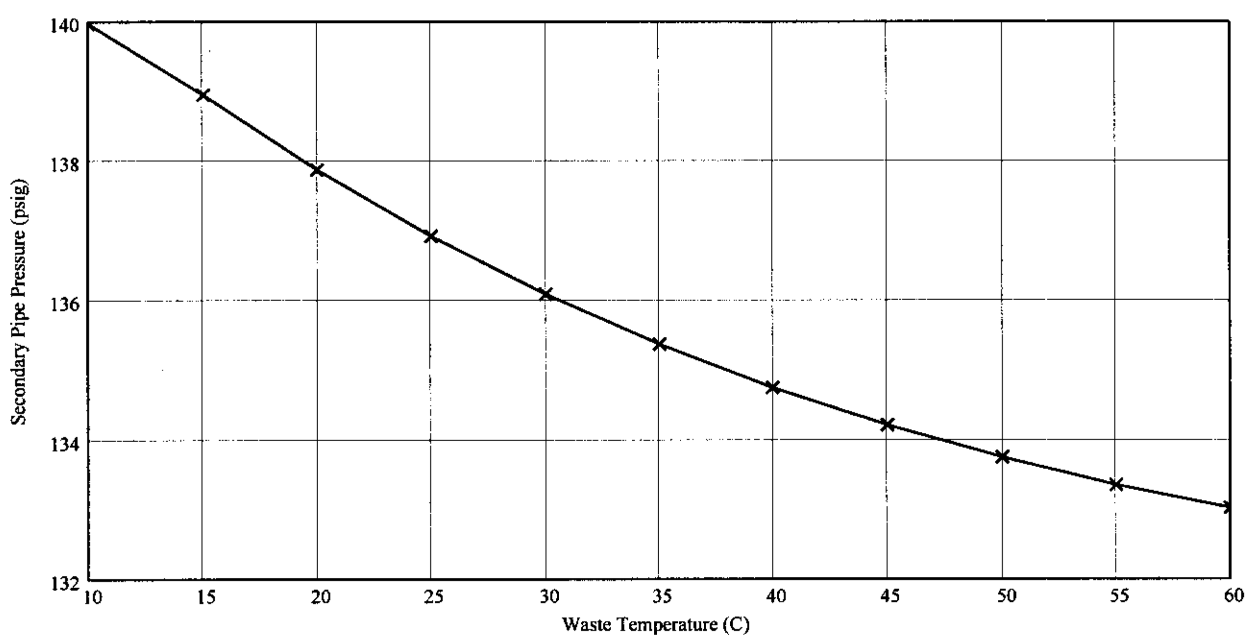
Figure 6b. Pressure in Secondary Encasement Pipe as a Function of Waste Temperature Due to Primary Pipe Break at x_B within Encasement Section with Two 1-in. Drains in Encasement Section of Length L_s Starting at L_o Relative to Pump.

$Z = 25\,ft$ $p_{dh} = 650\,psi$ $\rho = 1.5\,\frac{kg}{liter}$ $\varepsilon_P = 2\,mil$ $\varepsilon_S = 50\,mil$ $\varepsilon_D = 50\,mil$

$H = 17.5\,ft$ $L_S = 4000\,ft$ $L_o = 0\,ft$ $L_P = 7000\,ft$ $L_i = 9\,ft$ $L_j = 108\,ft$ $x_B = 0\,ft$ $F_{D6} = 1$

$\Delta Z_D = -1\,ft$ $D_{Di} = 1.049\,in$ $F_{D9} = 1$

$L_D(D_{Di}) = 10.9\,ft$



Effect of Waste Bulk Density

$$\rho\rho(L_o, L_S, x_B, \rho, t_C, p_{dh}, \varepsilon_P, \varepsilon_S, \varepsilon_D, D_{Di}, F_{D6}, F_{D9}, \Delta Z_D, L_P, H, Z, n) :=$$

```
vp ← 0
for i ∈ 0..length(ρ) − 1
    ρ_DD ← ρ_i
    p ← 0
    p ← ff(L_o, L_S, x_B, ρ_DD, t_C, p_dh, ε_P, ε_S, ε_D, D_Di, F_D6, F_D9, ΔZ_D, L_P
    vp_i ← p_n,0
vp
```

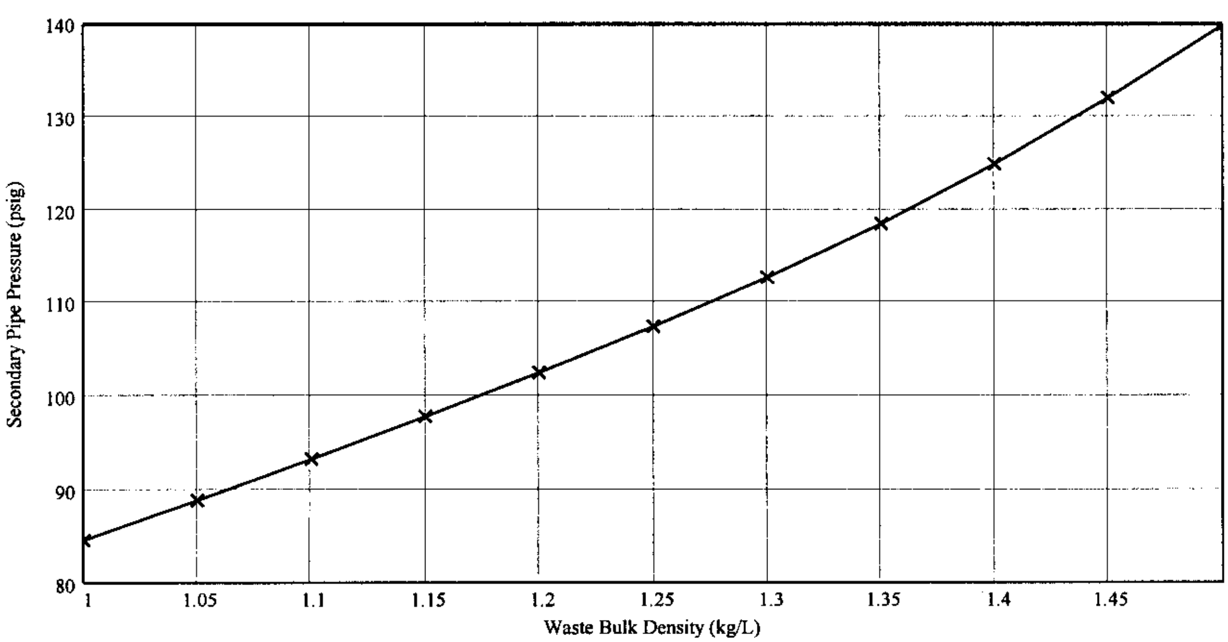
Figure 6c. Pressure in Secondary Encasement Pipe as a Function of Waste Bulk Density Due to Primary Pipe Break at x_B within Encasement Section with Two 1-in. Drains in Encasement Section of Length L_s Starting at L_o Relative to Pump.

$Z = 25\,ft$ $p_{dh} = 650\,psi$ $t_C = 10\ ^\circ C$ $\varepsilon_P = 2\,mil$ $\varepsilon_S = 50\,mil$ $\varepsilon_D = 50\,mil$

$H = 17.5\,ft$ $L_S = 4000\,ft$ $L_o = 0\,ft$ $L_P = 7000\,ft$ $L_i = 9\,ft$ $L_j = 108\,ft$ $x_B = 0\,ft$ $F_{D6} = 1$

$\Delta Z_D = -1\,ft$ $D_{Di} = 1.049\,in$ $F_{D9} = 1$

$L_D(D_{Di}) = 10.9\,ft$



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EVALUATION ANALYSIS

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Client: CH2M Hill Hanford Group, Inc. WO/Job No. ______
Subject: Secondary Encasement Pipe Pressure Due to Primary Pipe Break in Waste Tank Transfer Piping System
Date: 09/07/2000 By: L. J. Julyk
Checked: 09/08/2000 By: T. C. Oten
Location: 200 Area - Hanford Site, Richland, Washington
Revised: ______ By: ______

Low Point (One) Drain Case - Upward Sloping Pipe (H> 0) - 1-in. Drain

Input=======Maximum Pressure===================

$L_o := 0 \cdot ft$ $\quad p_{dh} := 650 \cdot psi$ $\quad H = 17.5\,ft$ $\quad \varepsilon_P := 2 \cdot mil$

$L_S := 4000 \cdot ft$ $\quad \rho := 1.5 \cdot \frac{kg}{liter}$ $\quad Z := 25 \cdot ft$ $\quad \varepsilon_S := 50 \cdot mil$

$L_P = 7000\,ft$ $\quad F_{D6} := 1$ $\quad \varepsilon_D := 50 \cdot mil$

$x_B := 0 \cdot ft + L_o$ $\quad t_C := 10\ ^oC$ $\quad F_{D9} := 0$ $\quad D_{Di} = 1.049\,in$ $\quad \Delta Z_D = -1\,ft$ $\quad L_D(D_{Di}) = 10.9\,ft$

$$\begin{pmatrix} h_P \\ P_2 \\ P_3 \\ P_5 \\ P_6 \\ P_8 \\ P_9 \\ v_1 \\ v_3 \\ v_5 \\ v_6 \\ v_8 \\ v_9 \end{pmatrix} := ff(L_o, L_S, x_B, \rho, t_C, p_{dh}, \varepsilon_P, \varepsilon_S, \varepsilon_D, D_{Di}, F_{D6}, F_{D9}, \Delta Z_D, L_P, H, Z)$$

Results---

$h_P = 340.7\,ft$ $\quad H'_p(A_P \cdot v_1, p_{dh}) = 340.7\,ft$ $\quad \mu_t := \mu(\rho, t_C)$ $\quad \mu_t = 11.708\,cP$ $\quad L_i = 9\,ft$ $\quad L_j = 108\,ft$ $\quad D_{Di} = 1.049\,in$

$P_2 = 221.5\,psi$ $\quad v_1 = 10.2\,ft\,sec^{-1}$ $\quad A_P \cdot v_1 = 234.7\,gpm$ $\quad \frac{\varepsilon_P}{D_{Pi}} = 0.00065$ $\quad \frac{\varepsilon_S}{D_{H\_annulus}} = 0.01949$ $\quad \frac{\varepsilon_D}{D_{Di}} = 0.04766$

$P_3 = 222.3\,psi$ $\quad v_3 = 4.9\,ft\,sec^{-1}$ $\quad A_P \cdot v_3 = 113.1\,gpm$

$P_5 = 222.5\,psi$ $\quad v_5 = 2\,ft\,sec^{-1}$ $\quad A_S \cdot v_5 = 121.6\,gpm$

$P_6 = 201.4\,psi$ $\quad v_6 = 45.1\,ft\,sec^{-1}$ $\quad F_{D6} \cdot A_f(D_{Di}) \cdot v_6 = 121.6\,gpm$

$v_8 = 0\,ft\,sec^{-1}$ $\quad A_S \cdot v_8 = 0\,gpm$

$F_{D9} \cdot A_f(D_{Di}) \cdot v_9 = 0\,gpm$

$$v_1 \cdot A_P \;=\; A_P \cdot v_3 + A_S \cdot v_5 + A_S \cdot v_8 = 234.7\,gpm$$

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Client:	CH2M Hill Hanford Group, Inc.	WO/Job No.	
Subject:	Secondary Encasement Pipe Pressure Due to Primary Pipe Break in Waste Tank Transfer Piping System	Date: 09/07/2000 Checked: 09/08/2000	By: L. J. Julyk By: T. C. Oten
Location:	200 Area - Hanford Site, Richland, Washington	Revised:	By:

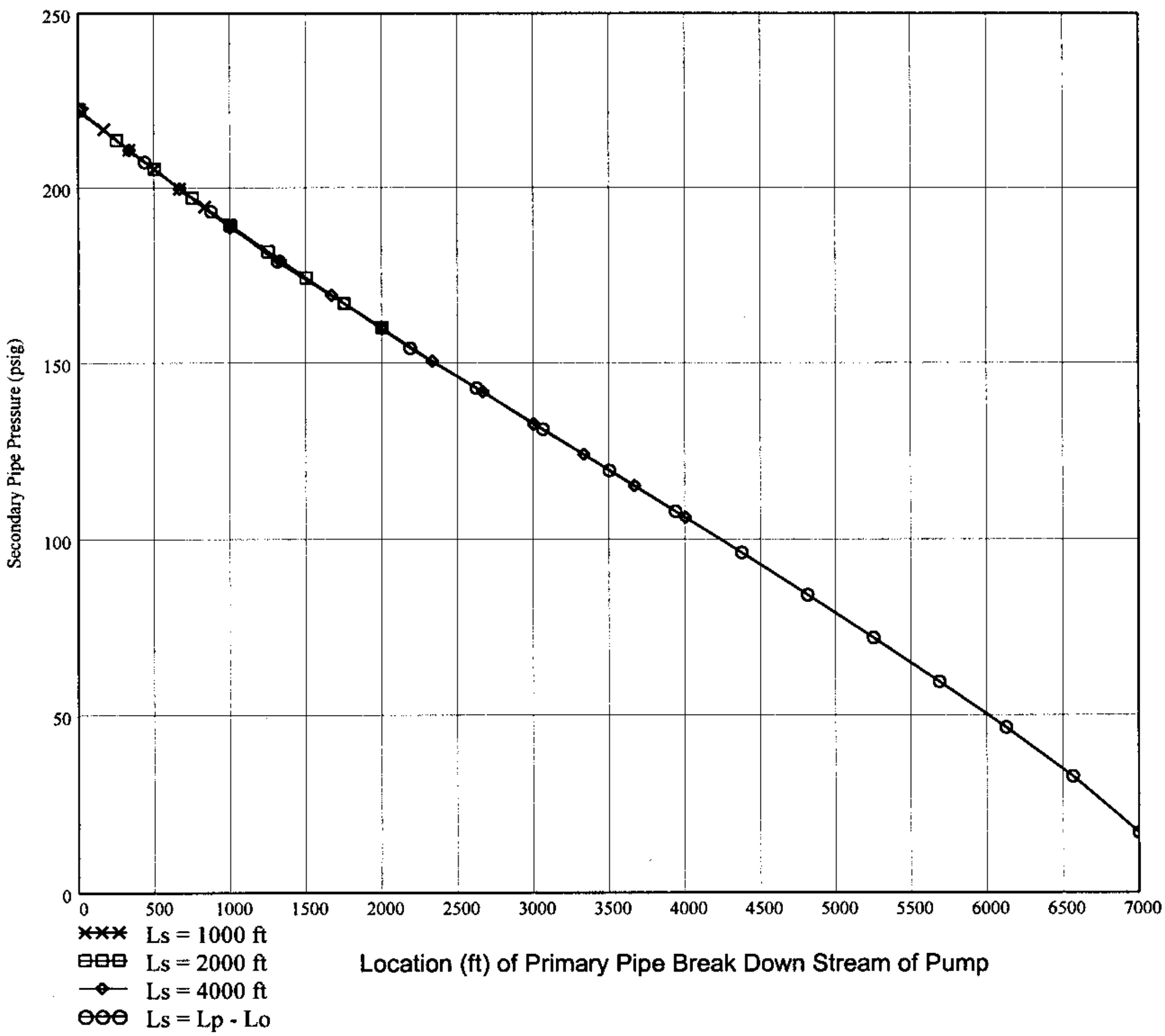
Figure 7. Low Point (One) 1-in. Drain Case - Upward Sloping Pipe (H> 0) Maximum Pressure in Secondary Encasement Pipe Due to Primary Pipe Break within Encasement Section with Low Point Drain in Encasement Section of Length L_s

Starting at L_o = 0 ft Relative to Pump and for a Waste Temperature of 10 °C.

$Z = 25\,ft$ $p_{dh} = 650\,psi$ $\rho = 1.5\frac{kg}{liter}$ $\mu(\rho,t_C) = 11.708\,cP$ $\varepsilon_P = 2\,mil$ $\varepsilon_S = 50\,mil$ $\varepsilon_D = 50\,mil$ $F_{D6} = 1$

$H = 17.5\,ft$ $t_C = 10\ ^\circ C$ $L_o = 0\,ft$ $L_P = 7000\,ft$ $L_i = 9\,ft$ $L_j = 108\,ft$ $D_{Di} = 1.049\,in$ $F_{D9} = 0$

$\Delta Z_D = -1\,ft$ $L_D(D_{Di}) = 10.9\,ft$



CH2MHILL Hanford Group, Inc.
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Client: CH2M Hill Hanford Group, Inc.
Subject: Secondary Encasement Pipe Pressure Due to Primary Pipe Break in Waste Tank Transfer Piping System
Location: 200 Area - Hanford Site, Richland, Washington

WO/Job No. ______
Date: 09/07/2000 By: L. J. Julyk
Checked: 09/08/2000 By: T. C. Oten
Revised: ______ By: ______

Low Point (One) Drain Case - Downward Sloping Pipe (H<0) - 1-in. Drain

Input=======Maximum Pressure====================

$L_o := 0 \cdot ft$ $p_{dh} := 650 \cdot psi$ $H := -0.25 \cdot \% \cdot L_P$ $\varepsilon_P := 2 \cdot mil$

$L_S := 4000 \cdot ft$ $\rho := 1.5 \cdot \frac{kg}{liter}$ $Z := 25 \cdot ft$ $\varepsilon_S := 50 \cdot mil$

$L_P = 7000\,ft$ $F_{D6} := 0$ $\varepsilon_D := 50 \cdot mil$

$x_B := 0 \cdot ft + L_o$ $t_C := 10\ ^oC$ $F_{D9} := 1$ $D_{Di} = 1.049\,in$ $\Delta Z_D = -1\,ft$ $L_D(D_{Di}) = 10.9\,ft$

$$\begin{pmatrix} h_P \\ P_2 \\ P_3 \\ P_5 \\ P_6 \\ P_8 \\ P_9 \\ v_1 \\ v_3 \\ v_5 \\ v_6 \\ v_8 \\ v_9 \end{pmatrix} := ff(L_o, L_S, x_B, \rho, t_C, p_{dh}, \varepsilon_P, \varepsilon_S, \varepsilon_D, D_{Di}, F_{D6}, F_{D9}, \Delta Z_D, L_P, H, Z)$$

Results---

$h_P = 366.9\,ft$ $H'_p(A_P \cdot v_1, p_{dh}) = 366.9\,ft$ $\mu_t := \mu(\rho, t_C)$ $\mu_t = 11.708\,cP$ $L_i = 9\,ft$ $L_j = 108\,ft$ $D_{Di} = 1.049\,in$

$P_2 = 238.6\,psi$ $v_1 = 10\,ft\,sec^{-1}$ $A_P \cdot v_1 = 230\,gpm$

$P_3 = 239.3\,psi$ $v_3 = 5.4\,ft\,sec^{-1}$ $A_P \cdot v_3 = 125.5\,gpm$

$\frac{\varepsilon_P}{D_{Pi}} = 0.00065$ $\frac{\varepsilon_S}{D_{H\_annulus}} = 0.01949$ $\frac{\varepsilon_D}{D_{Di}} = 0.04766$

$v_5 = 0\,ft\,sec^{-1}$ $A_S \cdot v_5 = 0\,gpm$

$F_{D6} \cdot A_f(D_{Di}) \cdot v_6 = 0\,gpm$

$P_8 = 239.6\,psi$ $v_8 = 1.7\,ft\,sec^{-1}$ $A_S \cdot v_8 = 104.4\,gpm$

$P_9 = 148.6\,psi$ $v_9 = 38.8\,ft\,sec^{-1}$ $F_{D9} \cdot A_f(D_{Di}) \cdot v_9 = 104.4\,gpm$

$v_1 \cdot A_P = A_P \cdot v_3 + A_S \cdot v_5 + A_S \cdot v_8 = 230\,gpm$

(continuity check at break, OK)

Client: CH2M Hill Hanford Group, Inc.
Subject: Secondary Encasement Pipe Pressure Due to Primary Pipe Break in Waste Tank Transfer Piping System
Location: 200 Area - Hanford Site, Richland, Washington

WO/Job No. ______
Date: 09/07/2000 By: L. J. Julyk
Checked: 09/08/2000 By: T. C. Oten
Revised: ______ By: ______

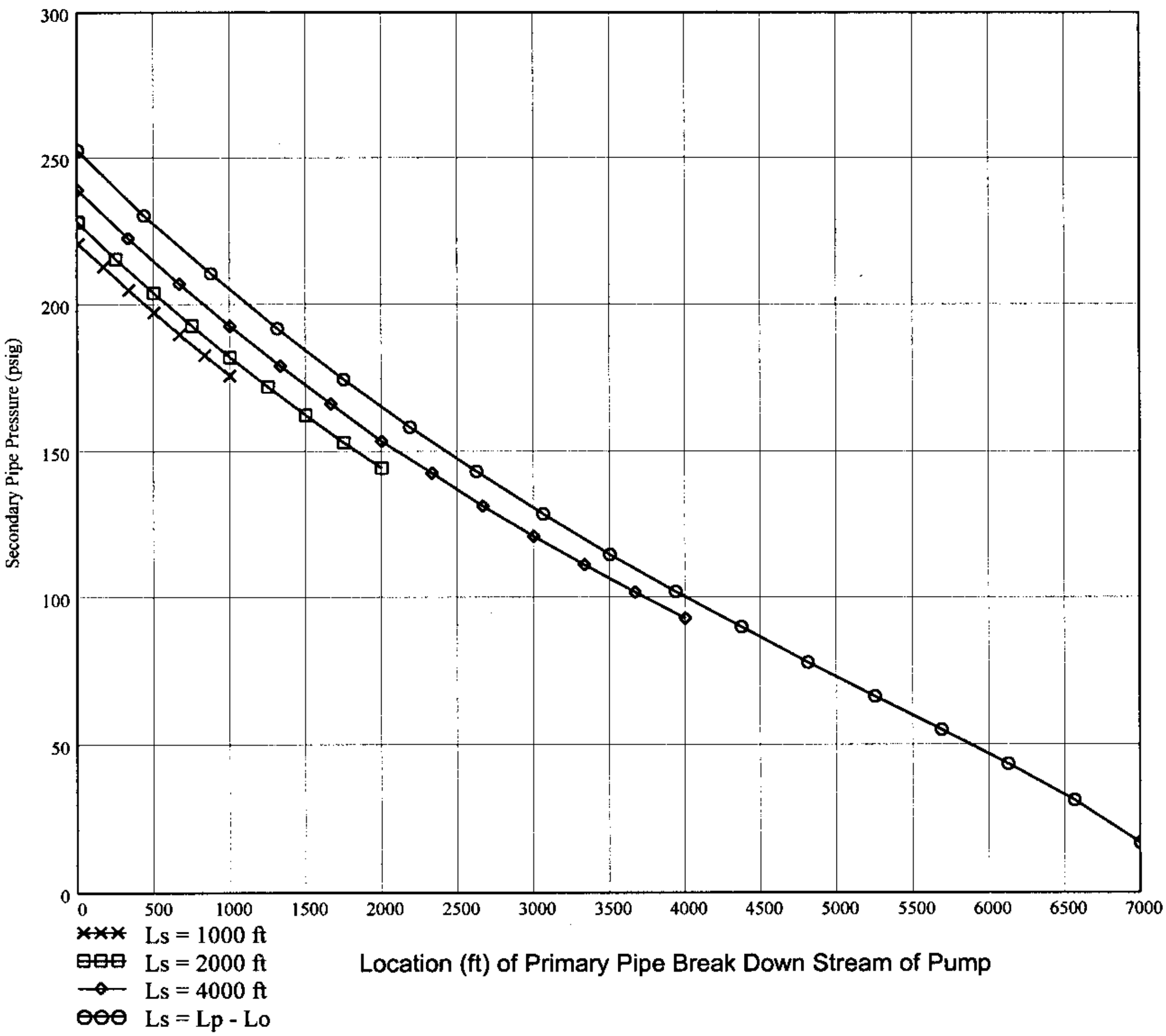
$n := 5$

Figure 8. Low Point (One) 1-in. Drain Case - Downward Sloping Pipe (H<0)
Maximum Pressure in Secondary Encasement Pipe Due to Primary Pipe Break within Encasement Section with Low Point Drain in Encasement Section of Length L_s
Starting at L_o = 0 ft Relative to Pump and for a Waste Temperature of 10 °C.

$Z = 25\,ft$ $p_{dh} = 650\,psi$ $\rho = 1.5\,\frac{kg}{liter}$ $\mu(\rho, t_C) = 11.708\,cP$ $\varepsilon_P = 2\,mil$ $\varepsilon_S = 50\,mil$ $\varepsilon_D = 50\,mil$ $F_{D6} = 0$

$H = -17.5\,ft$ $t_C = 10\ ^{\circ}C$ $L_o = 0\,ft$ $L_P = 7000\,ft$ $L_i = 9\,ft$ $L_j = 108\,ft$ $D_{Di} = 1.049\,in$ $F_{D9} = 1$

$\Delta Z_D = -1\,ft$ $L_D(D_{Di}) = 10.9\,ft$



Two Drain Case - 2-in. Drain

$n := 3$

Input=======Maximum Pressure====================

$L_o := 0 \cdot ft$ $\quad p_{dh} := 650 \cdot psi$ $\quad H = -17.5\,ft$ $\quad \varepsilon_P := 2 \cdot mil$

$L_S := 4000 \cdot ft$ $\quad \rho := 1.5 \cdot \frac{kg}{liter}$ $\quad Z := 25 \cdot ft$ $\quad \varepsilon_S := 50 \cdot mil$

$L_P := 7000 \cdot ft$ $\quad F_{D6} := 1$ $\quad \varepsilon_D := 50 \cdot mil$

$x_B := 1333 \cdot ft + L_o$ $\quad t_C := 10\ °C$ $\quad F_{D9} := 1$ $\quad D_{Di} := D_{D2i}$ $\quad \Delta Z_D = -1\,ft$ $\quad L_D(D_{Di}) = 18.5\,ft$

$$\begin{pmatrix} h_P \\ P_2 \\ P_3 \\ P_5 \\ P_6 \\ P_8 \\ P_9 \\ v_1 \\ v_3 \\ v_5 \\ v_6 \\ v_8 \\ v_9 \end{pmatrix} := ff(L_o, L_S, x_B, \rho, t_C, p_{dh}, \varepsilon_P, \varepsilon_S, \varepsilon_D, D_{Di}, F_{D6}, F_{D9}, \Delta Z_D, L_P, H, Z)$$

Results--

$h_P = 284.1\,ft$ $\quad H'_p(A_P \cdot v_1, p_{dh}) = 284.1\,ft$ $\quad \mu_t := \mu(\rho, t_C)$ $\quad \mu_t = 11.708\,cP$ $\quad L_i = 9\,ft$ $\quad L_j = 108\,ft$ $\quad D_{Di} = 2.067\,in$

$P_2 = 39.1\,psi$ $\quad v_1 = 10.6\,ft\,sec^{-1}$ $\quad A_P \cdot v_1 = 244.5\,gpm$ $\quad \frac{\varepsilon_P}{D_{Pi}} = 0.00065$ $\quad \frac{\varepsilon_S}{D_{H\_annulus}} = 0.01949$ $\quad \frac{\varepsilon_D}{D_{Di}} = 0.02419$

$P_3 = 40.2\,psi$ $\quad v_3 = 2\,ft\,sec^{-1}$ $\quad A_P \cdot v_3 = 46.3\,gpm$

$P_5 = 40.2\,psi$ $\quad v_5 = 1.8\,ft\,sec^{-1}$ $\quad A_S \cdot v_5 = 109.9\,gpm$

$P_6 = 7\,psi$ $\quad v_6 = 10.5\,ft\,sec^{-1}$ $\quad F_{D6} \cdot A_f(D_{Di}) \cdot v_6 = 109.9\,gpm$

$P_8 = 40.2\,psi$ $\quad v_8 = 1.5\,ft\,sec^{-1}$ $\quad A_S \cdot v_8 = 88.3\,gpm$

$P_9 = 4.3\,psi$ $\quad v_9 = 8.4\,ft\,sec^{-1}$ $\quad F_{D9} \cdot A_f(D_{Di}) \cdot v_9 = 88.3\,gpm$

$$v_1 \cdot A_P = A_P \cdot v_3 + A_S \cdot v_5 + A_S \cdot v_8 = 244.5\,gpm$$

(continuity check at break, OK)

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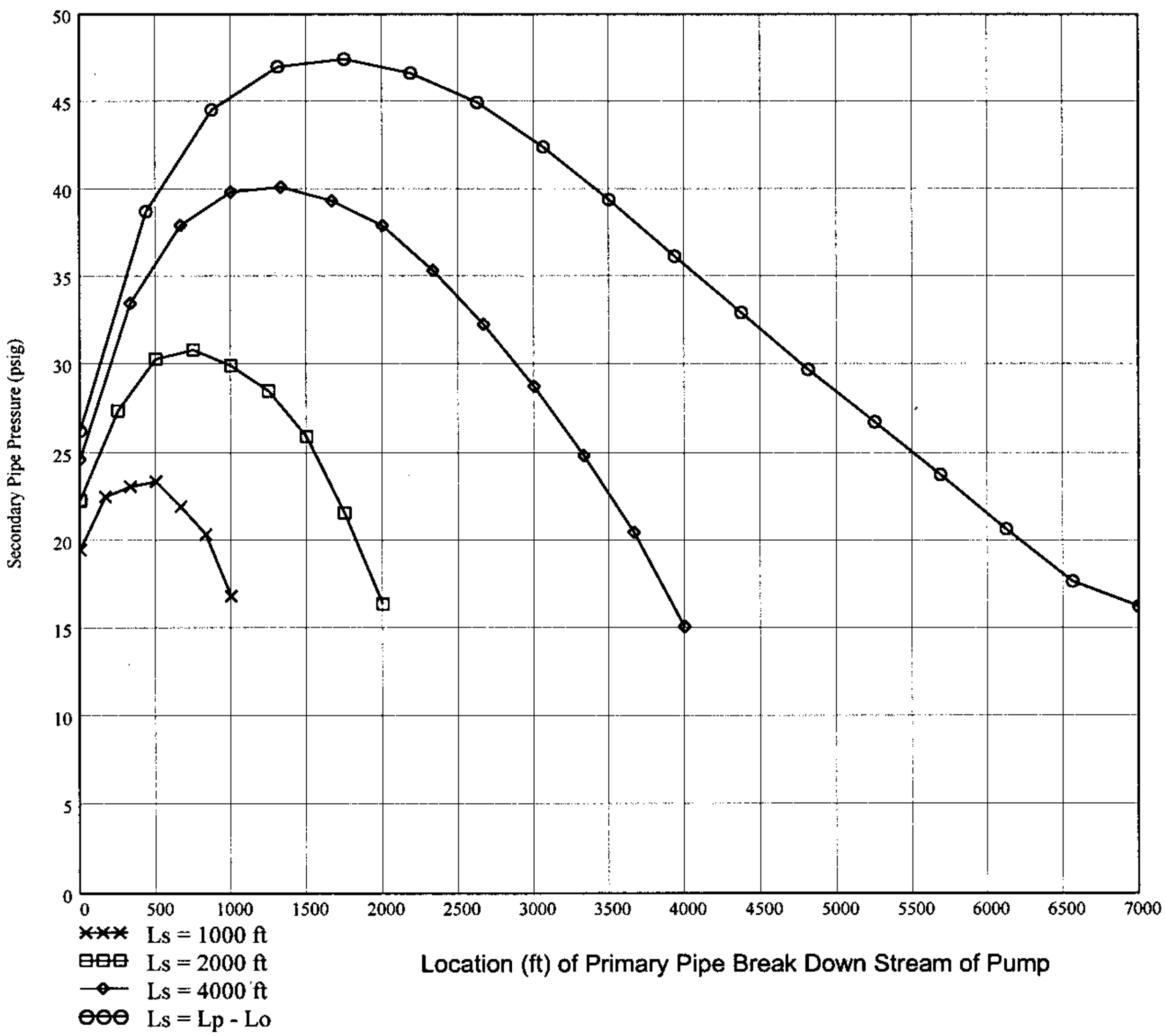
	Checked: 09/08/2000	By: T. C. Oten	
Location: 200 Area - Hanford Site, Richland, Washington	Revised:	By:	

Figure 9. Maximum Pressure in Secondary Encasement Pipe Due to Primary Pipe Break within Encasement Section with Two 2-in. Drains in Encasement Section of Length L_s Starting at L_o = 0 ft Relative to Pump and for a Waste Temperature of 10 °C.

$Z = 25\,ft$ $p_{dh} = 650\,psi$ $\rho = 1.5\,\frac{kg}{liter}$ $\mu(\rho, t_C) = 11.708\,cP$ $\varepsilon_P = 2\,mil$ $\varepsilon_S = 50\,mil$ $\varepsilon_D = 50\,mil$ $F_{D6} = 1$

$H = -17.5\,ft$ $t_C = 10\ {}^\circ C$ $L_o = 0\,ft$ $L_P = 7000\,ft$ $L_i = 9\,ft$ $L_j = 108\,ft$ $D_{Di} = 2.067\,in$ $F_{D9} = 1$

$\Delta Z_D = -1\,ft$ $L_D(D_{Di}) = 18.5\,ft$



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Location: 200 Area - Hanford Site, Richland, Washington

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Checked: 09/08/2000 By: T. C. Oten
Revised: ____ By: ____

Low Point (One) Drain Case - Upward Sloping Pipe (H> 0) - 2-in. Drain

Input======Maximum Pressure===================

$L_o := 0 \cdot ft$ $p_{dh} := 650 \cdot psi$ $H = -17.5\,ft$ $\varepsilon_P := 2 \cdot mil$

$L_S := 4000 \cdot ft$ $\rho := 1.5 \cdot \frac{kg}{liter}$ $Z := 25 \cdot ft$ $\varepsilon_S := 50 \cdot mil$

$L_P = 7000\,ft$ $F_{D6} := 1$ $\varepsilon_D := 50 \cdot mil$

$x_B := 2333 \cdot ft + L_o$ $t_C := 10\ {}^oC$ $F_{D9} := 0$ $D_{Di} = 2.067\,in$ $\Delta Z_D = -1\,ft$ $L_D(D_{Di}) = 18.5\,ft$

$$\begin{pmatrix} h_P \\ P_2 \\ P_3 \\ P_5 \\ P_6 \\ P_8 \\ P_9 \\ v_1 \\ v_3 \\ v_5 \\ v_6 \\ v_8 \\ v_9 \end{pmatrix} := ff(L_o, L_S, x_B, \rho, t_C, p_{dh}, \varepsilon_P, \varepsilon_S, \varepsilon_D, D_{Di}, F_{D6}, F_{D9}, \Delta Z_D, L_P, H, Z)$$

Results---

$h_P = 444.7\,ft$ $H'_p(A_P \cdot v_1, p_{dh}) = 444.7\,ft$ $\mu_t := \mu(\rho, t_C)$ $\mu_t = 11.708\,cP$ $L_i = 9\,ft$ $L_j = 108\,ft$ $D_{Di} = 2.067\,in$

$P_2 = 87.6\,psi$ $v_1 = 9.3\,ft\,sec^{-1}$ $A_P \cdot v_1 = 215.3\,gpm$ $\frac{\varepsilon_P}{D_{Pi}} = 0.00065$ $\frac{\varepsilon_S}{D_{H\_annulus}} = 0.01949$ $\frac{\varepsilon_D}{D_{Di}} = 0.02419$

$P_3 = 88.3\,psi$ $v_3 = 3.7\,ft\,sec^{-1}$ $A_P \cdot v_3 = 85.7\,gpm$

$P_5 = 88.4\,psi$ $v_5 = 2.2\,ft\,sec^{-1}$ $A_S \cdot v_5 = 129.6\,gpm$

$P_6 = 10\,psi$ $v_6 = 12.4\,ft\,sec^{-1}$ $F_{D6} \cdot A_f(D_{Di}) \cdot v_6 = 129.6\,gpm$

$v_8 = 0\,ft\,sec^{-1}$ $A_S \cdot v_8 = 0\,gpm$

$F_{D9} \cdot A_f(D_{Di}) \cdot v_9 = 0\,gpm$

$v_1 \cdot A_P = A_P \cdot v_3 + A_S \cdot v_5 + A_S \cdot v_8 = 215.3\,gpm$

(continuity check at break, OK)

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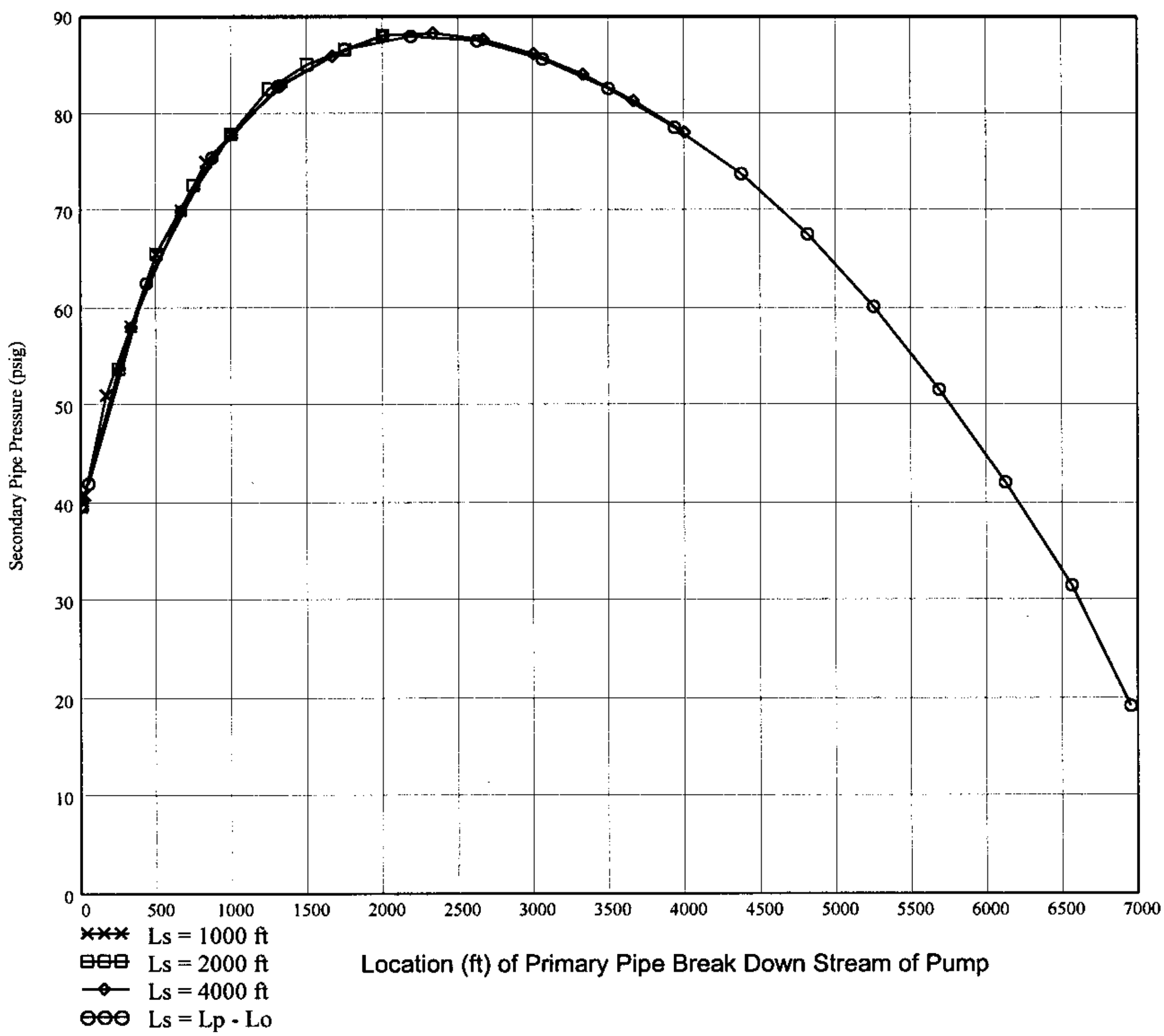
Figure 10. Low Point (One) 2-in. Drain Case - Upward Sloping Pipe (H> 0)
Maximum Pressure in Secondary Encasement Pipe Due to Primary Pipe Break within Encasement Section with Low Point Drain in Encasement Section of Length L_s

Starting at L_o = 0 ft Relative to Pump and for a Waste Temperature of 10 °C.

$Z = 25\,\text{ft}$ $p_{dh} = 650\,\text{psi}$ $\rho = 1.5\,\frac{\text{kg}}{\text{liter}}$ $\mu(\rho, t_C) = 11.708\,\text{cP}$ $\varepsilon_P = 2\,\text{mil}$ $\varepsilon_S = 50\,\text{mil}$ $\varepsilon_D = 50\,\text{mil}$ $F_{D6} = 1$

$H = -17.5\,\text{ft}$ $t_C = 10\,°\text{C}$ $L_o = 0\,\text{ft}$ $L_P = 7000\,\text{ft}$ $L_i = 9\,\text{ft}$ $L_j = 108\,\text{ft}$ $D_{Di} = 2.067\,\text{in}$ $F_{D9} = 0$

$\Delta Z_D = -1\,\text{ft}$ $L_D(D_{Di}) = 18.5\,\text{ft}$



Low Point (One) Drain Case - Downward Sloping Pipe (H<0) - 2-in. Drain

Input=======Maximum Pressure===================

$L_o := 0 \cdot ft$ $\quad p_{dh} := 650 \cdot psi$ $\quad H := -0.25 \cdot \% \cdot L_P$ $\quad \varepsilon_P := 2 \cdot mil$

$L_S := 4000 \cdot ft$ $\quad \rho := 1.5 \cdot \frac{kg}{liter}$ $\quad Z := 25 \cdot ft$ $\quad \varepsilon_S := 50 \cdot mil$

$L_P = 7000\,ft$ $\quad F_{D6} := 0$ $\quad \varepsilon_D := 50 \cdot mil$

$x_B := 0 \cdot ft + L_o$ $\quad t_C := 10\ ^oC$ $\quad F_{D9} := 1$ $\quad D_{Di} = 2.067\,in$ $\quad \Delta Z_D = -1\,ft$ $\quad L_D(D_{Di}) = 18.5\,ft$

$$\begin{pmatrix} h_P \\ P_2 \\ P_3 \\ P_5 \\ P_6 \\ P_8 \\ P_9 \\ v_1 \\ v_3 \\ v_5 \\ v_6 \\ v_8 \\ v_9 \end{pmatrix} := ff(L_o, L_S, x_B, \rho, t_C, p_{dh}, \varepsilon_P, \varepsilon_S, \varepsilon_D, D_{Di}, F_{D6}, F_{D9}, \Delta Z_D, L_P, H, Z)$$

Results---

$h_P = 256.2\,ft$ $\quad H'_p(A_P \cdot v_1, p_{dh}) = 256.2\,ft$ $\quad \mu_t := \mu(\rho, t_C)$ $\quad \mu_t = 11.708\,cP$ $\quad L_i = 9\,ft$ $\quad L_j = 108\,ft$ $\quad D_{Di} = 2.067\,in$

$P_2 = 166.6\,psi$ $\quad v_1 = 10.8\,ft\,sec^{-1}$ $\quad A_P \cdot v_1 = 249.2\,gpm$ $\quad \frac{\varepsilon_P}{D_{Pi}} = 0.00065$ $\quad \frac{\varepsilon_S}{D_{H\_annulus}} = 0.01949$ $\quad \frac{\varepsilon_D}{D_{Di}} = 0.02419$

$P_3 = 167.6\,psi$ $\quad v_3 = 4.4\,ft\,sec^{-1}$ $\quad A_P \cdot v_3 = 102.2\,gpm$

$v_5 = -0\,ft\,sec^{-1}$ $\quad A_S \cdot v_5 = -0\,gpm$

$F_{D6} \cdot A_f(D_{Di}) \cdot v_6 = 0\,gpm$

$P_8 = 167.7\,psi$ $\quad v_8 = 2.4\,ft\,sec^{-1}$ $\quad A_S \cdot v_8 = 147\,gpm$

$P_9 = 13\,psi$ $\quad v_9 = 14.1\,ft\,sec^{-1}$ $\quad F_{D9} \cdot A_f(D_{Di}) \cdot v_9 = 147\,gpm$

$$v_1 \cdot A_P \quad = \quad A_P \cdot v_3 + A_S \cdot v_5 + A_S \cdot v_8 = 249.2\,gpm$$

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Revised: ________ By: ________

$n := 5$

Figure 11. Low Point (One) 2-in. Drain Case - Downward Sloping Pipe (H<0) Maximum Pressure in Secondary Encasement Pipe Due to Primary Pipe Break within Encasement Section with Low Point Drain in Encasement Section of Length L_s

Starting at L_o = 0 ft Relative to Pump and for a Waste Temperature of 10 °C.

$Z = 25\,ft$ $p_{dh} = 650\,psi$ $\rho = 1.5\,\frac{kg}{liter}$ $\mu(\rho, t_C) = 11.708\,cP$ $\varepsilon_P = 2\,mil$ $\varepsilon_S = 50\,mil$ $\varepsilon_D = 50\,mil$ $F_{D6} = 0$

$H = -17.5\,ft$ $t_C = 10\ {}^{\circ}C$ $L_o = 0\,ft$ $L_P = 7000\,ft$ $L_i = 9\,ft$ $L_j = 108\,ft$ $D_{Di} = 2.067\,in$ $F_{D9} = 1$

$\Delta Z_D = -1\,ft$ $L_D(D_{Di}) = 18.5\,ft$