SECTION 5.0

# TANK STORAGE INFORMATION

## 5.1 INTRODUCTION

This section describes GLOBALFOUNDRIES' two waste storage tank systems located at the Building 974 Chemical Distribution Center (CDC) tank farm and at the north end of Building 963, and also gives information on the CDC container storage secondary containment tank at the CDC.

## 5.2 CDC TANK FARM

Bulk organic solvent wastes are stored in 10,000-gallon aboveground tanks at the CDC. There are five tanks which currently provide storage for general solvents as described in Table 3-1 and one out of service tank. The specific types of wastes allowed in each individual bulk tank are determined through the waste characterization and handling process described in Section 3.2.1. Table 5-1 provides a description of the physical characteristics of the tanks and Table 5-2 provides the volume of the tanks and the specific gravity of waste currently stored in them.

The tanks have been designed in accordance with the Rules of UL12C and were fabricated and stamped in accordance with the provisions of the American Society of Mechanical Engineers (ASME) Code Rules, Section VIII, Division 1, 1980 and 1995. The tanks are compatible with the wastes they contain and have a design working pressure of 20 pounds per square inch (psi). The Waste Mid UV Resist, Former Waste Deep UV Resist (Out of Service), General Solvent 1, and General Solvent 4 tanks are constructed of SA 285C carbon steel, while the Waste Deep UV Resist (Former General Solvent 2) and General Solvent 3 tanks are SA 240 type 304 stainless steel (see Figure D-2-1, Appendix D for tank details.) The tank assessment reports for these tanks, required per 40 CFR Parts 264.192 and 264.193, can be found in Appendix A. These reports were originally completed for IBM and will continue to be accepted by GLOBALFOUNDRIES.

Each tank is heated and insulated to prevent freezing of the contents during the winter. Heat is applied to the tanks with electrical heat tracing. The heat tracing system is provided with an external tank sensing thermostat, which energizes the heat tracing when the temperature falls below 55 degrees F. The heat tracing is then deactivated when the temperature reaches 55 degrees F or higher. All cables, connections, and thermostats are Factory Mutual approved for Class I, Division 2 areas. The insulation is covered with a 0.016-inch thick aluminum jacket. Heat tracing may be deactivated for tanks that are not in use or have been taken out of service.

The tanks are supported by three 120-degree steel saddles welded to the tank shell and placed on reinforced concrete with 3/8-inch bolts. The two end saddles are on slide mounts. For details on the support structures, see Figures D-2-1 and D-2-5, Appendix D. The tanks are placed in carbon-steel-lined containment vaults located on one-foot-thick reinforced concrete pads.

**Table 5-1**
**Physical Characteristics of CDC Storage Tanks**

| | Waste Mid UV, General Solvent 1, Out of Service Solvent Tank, and General Solvent 4 Tanks | Waste Deep UV and General Solvent 3 Tanks |
|---|---|---|
| Shell Material | Carbon Steel | 304 Stainless Steel |
| Shell Thickness | ¼ inches | ¼ inches |
| Diameter | 120 inches | 120 inches |
| Length | 15 feet | 15 feet |
| Seams long and girth | Double Butt Weld | Double Butt Weld |
| End Thickness | 3/16 inch | .215 inches |
| End Material | SA285C | SA 240 |

**Nozzles and Inspection Openings**

| Number | Size (inches) | Waste Mid UV, General Solvent 1, Out Of Service, and General Solvent 4 Tanks | Waste Deep UV and General Solvent 3 Tanks |
|---|---|---|---|
| 1 | 10 | SA53B | SA 312/182 |
| 1 | 5 | SA53B | SA 312/182 |
| 1 | 6 | SA53B | SA 312/182 |
| 2 | 2 | SA53B | SA 312/182 |
| 2 | 2 | SA53B | SA 312/182 |
| 2 | 24 (manhole) | SA285C | SA 240 |

**Supports:** three 120-degree saddles

## 5.3 BUILDING 963 NORTH TANK

Bulk organic solvent wastes may also be stored in one, 9,000-gallon closed, aboveground tank located in a steel lined containment vault north of Building 963. The specific gravity of the general solvent stored in the Building 963 Tank is 0.8-1.1. The physical characteristics of the tank are outlined in Table 5-3.

The tank was fabricated and stamped in accordance with the ASME rules. The tank consists of the 9,000-gallon tank mounted on three saddles and located in a stainless steel lined concrete containment vault. See Figure D-2-2 (Appendix D) for containment vault details. The tank assessment report for this tank, per 40 CFR Parts 264.192 and 264.193, can be found in Appendix A. The tank assessment report also contains tank design drawings and specifications.

| Table 5-2<br>Tank Capacity and Specific Gravity of Waste Stored In CDC Tanks | | |
|---|---|---|
| **Tank Name** | **Tank Capacity (gallons)** | **Specific Gravity** |
| Waste Mid UV Resist / PGMEA (formerly called N Butyl Acetate #1) | 10,000 | 0.88 - 1.1 |
| General Solvent # 1 | 10,000 | 0.8 - 1.1 |
| Out of Service Solvent Tank (Former Waste Deep UV Resist) | 10,000 | 0.8 - 1.1 |
| General Solvent # 3 (currently storing glycol solutions) | 10,000 | 0.8 - 1.1 |
| General Solvent # 4 | 10,000 | 0.8 - 1.1 |
| Waste Deep UV Resist/PGMEA (Formerly General Solvent 2) | 10,000 | 0.8 - 1.1 |

| Table 5-3<br>Physical Characteristics of Building 963<br>North Tank | |
|---|---|
| **Shell Material** | Stainless Steel |
| Shell Thickness | ¼ inch |
| Diameter | 108 inches |
| Length | 19 feet |
| Seams | Welded |
| End Thickness | ¼ inch |
| End Material | Stainless Steel |
| **Nozzles and Inspection Openings** | |
| **Number** | **Diameter (inches)** |
| 4 | 4 |
| 1 | 8 |
| 1 | 10 |
| 2 | 24 (manhole) |

## 5.4 CDC CONTAINER STORAGE SECONDARY CONTAINMENT TANK

As discussed in Section 4.3, a 3,000-gallon tank within the Empty Drum Storage Room in the CDC provides secondary containment for organic liquids stored in the CDC Waste Storage Room. Table 5-4 provides details of the tank servicing the CDC Waste Storage Room. The tank is located in a carbon-steel-lined vault within the Empty Drum Storage Room of the CDC building. The tank is constructed of welded carbon steel, built and tested in accordance with U.L. 142 standards. The shell and ends are #7 gauge. See Figure D-2-C (Appendix D) for additional tank details. The tank rests on three standard carbon steel cradles.

**Table 5-4**
**CDC Container Storage Secondary Containment Tank Capacity and Dimensions**

| Tank Name | Capacity (gallons) | Diameter (inches) | Length (inches) |
|---|---|---|---|
| CDC Container Storage Secondary Containment | 3,000 | 64 | 216 |

## 5.5 TANK CORROSION AND EROSION

Four of the six organic waste tanks at the CDC and the waste tank at Building 963 are carbon steel tanks. Carbon steel is resistant to organic wastes that are stored at GLOBALFOUNDRIES. The Waste Deep UV Resist and Waste General Solvent 3 tanks are stainless (304) steel and are also resistant to the organics stored in them. These tanks are inspected to ensure proper operation. A discussion of the inspection procedures is provided in Section 7.4.

Any waste tank that is determined to be unfit for operation due to a leak or being otherwise unfit for use must be taken out of service. The tank must not be returned to service unless GLOBALFOUNDRIES has repaired the system and obtained a certification by a qualified independent Vermont licensed professional engineer in accordance with §7-108(d) of the Vermont Hazardous Waste Management Regulations that the repaired system is capable of handling hazardous wastes without release for the intended life of the system. This certification must be placed in the operating record and maintained until closure of the facility.

The CDC container storage secondary containment tank is carbon steel, which is resistant to the organic and inorganic materials that may be stored within the CDC Waste Storage Room. The tank is not used for routine storage and would only be used in the event of a release.

## 5.6 TANK MANAGEMENT PRACTICES

This section provides the tank management practices for GLOBALFOUNDRIES' two tank storage systems (i.e., the CDC tank farm and the Building 963 tank) and also for the CDC container storage secondary containment tank.

### 5.6.1 Tank Piping

#### 5.6.1.1 CDC Tank Farm

Organic solvent wastes are pumped to the bulk tanks from the various manufacturing buildings through 2-inch pipes. (See Figure D-2-4 for a process flow diagram of the bulk tanks.) Wastes may also be received from the CDC Transfer Room. The CDC Transfer Room is described in Section 4.2.3.

When the tank levels reach a predetermined point, the tanks are pumped out and wastes are shipped to treatment, incineration, or reclamation facilities. (See Figure D-2-4, Appendix D for details of the tank farm piping.) Piping secondary containment is provided by double-walled piping and a pan-type system that discharges to the tank containment basins. Calculations are provided in Attachment 5-1 and Attachment 5-2 that demonstrate the ability of the secondary containment of the tanks and the piping containment pans to protect surrounding earth likely to come in contact with the waste if the waste is released from the system.

Details on the construction of the waste piping between the tank farm and the manufacturing facility (at Building 963) are provided in Figures D-2-11 through D-2-14. The waste piping route within the manufacturing buildings is shown in Figure D-2-16. Characteristic and listed wastes (n-Butyl acetate, IPA, ethylene glycol solutions, etc.) may be pumped to the Biological Waste Treatment Plant (BWTP) if the tank contents are determined to be treatable under the GLOBALFOUNDRIES National Pollutant Discharge Elimination System permit. The piping route from the CDC tank farm to the BWTP is shown in Figure D-2-15. The waste piping schematic for the tank farm is in Figure D-2-4.

The system as designed meets the requirements of 40 CFR 264.192 and 193, and 40 CFR 270.16 for new tank systems. The leak-detection monitoring system and the double-walled piping system provide adequate protection of human health and the environment. GLOBALFOUNDRIES provides secondary containment through the use of double-walled piping, flanges, welded joints and connections, and automatic shut-off devices for the piping system to safeguard the environment.

5.6.1.2 <u>Building 963 North Tank</u>

Organic solvent can be diverted from the various manufacturing buildings to the building 963 north tank (instead of being pumped to the CDC tank farm) in the event of a leak within the piping trestle, CDC, or CDC tank farm or to perform maintenance, repairs, or internal tank inspections within the trestle or CDC tank farm. Once the use of the tank is complete, the tank contents can either be pumped over to the CDC for storage in General Solvent #4, vacuumed out using a vacuum truck and brought to the CDC for storage, or vacuumed out directly to a tank truck for shipment to treatment, incineration, or reclamation facilities.

The waste piping schematic for the building 963 north tank is provided in Figure D-2-A. Piping secondary containment is provided by double-walled piping that discharges to the tank containment vault. The containment vault is designed at 170% of the tank capacity, as calculated in Section 5.6.6.3, which allows adequate protection to surrounding earth from both tank and waste piping releases.

The system as designed meets the requirements of 40 CFR 264.192 and 193, and 40 CFR 270.16 for new tank systems. The leak-detection monitoring system and the double-walled piping system provide adequate protection of human health and the environment. GLOBALFOUNDRIES provides secondary containment through the use of double-walled piping, flanges, welded joints and connections, and automatic shut-off devices for the piping system to safeguard the environment.

5.6.2 Level Controls

5.6.2.1 CDC Tank Farm

The six CDC waste tanks are equipped with liquid level sensors to monitor tank volume. The level sensors transmit a signal to the CDC Control Center where a digital display provides volume read-outs in gallons. High levels are indicated by warning lights on the tank control panel at the CDC Control Center. The high-level set point is approximately 70 percent of the tank volume or 7,000 gallons. Personnel in the Control Center monitor the tank control panel. In addition, a high level switch is mounted in one of the manways of the tanks that will shut a valve on the fill line to the tank in the event that the volume of waste in the tank exceeds 9,000 gallons.

5.6.2.2 Building 963 North Tank

The 9,000 gallon tank at Building 963 is equipped with a liquid level sensor. The level sensor transmits a signal to the Building 963 Chemical Control Center where a digital display provides volume read-outs in gallons. The tank has a high-level alarm which activates a pager notification when the volume in the tank reaches 5,000 gallons. The Building 963 tank is also equipped with a high-high-level switch that will stop the flow of waste to the tank if the volume of waste in the tank reaches 8,000 gallons. The building 963 tank level display and alarm are located in the Building 963 Chemical Control Center. Personnel monitor the level control daily when the tank is in use.

5.6.2.3 CDC Container Storage Secondary Containment Tank

The level in the CDC container storage secondary containment tank is monitored by liquid level sensors. The level sensors transmit a signal to the CDC Control Center. A pager notification is also activated when liquid starts to accumulate in the tank or containment vault. See Figure D-2-C (Appendix D) for details on the CDC container storage secondary containment tank.

5.6.3 Tank Venting

5.6.3.1 CDC Tank Farm

The six CDC waste tanks are equipped with 2-inch combination vacuum relief valves and flame arrestors made of carbon steel. All tanks are equipped with 6-inch emergency pressure relief vents made of aluminum with stainless steel trim and pallet.

5.6.3.2 Building 963 North Tank

The tank at Building 963 is equipped with a conservation vent and flame arrestor.

5.6.3.3 CDC Container Storage Secondary Containment Tank

The CDC container storage secondary containment tank is equipped with a 2-inch vent pipe of black steel.

5.6.4 Waste Shutoff

The six CDC waste tanks and the tank at Building 963 are equipped with manual and automatic valves to stop the incoming waste flow if a high level condition exists. (See Figures D-2-A and D-2-B for piping and instrumentation diagrams of the tanks).

5.6.5 Waste Transfer and Removal

5.6.5.1 CDC Tank Farm

Typically, when the tanks at the CDC tank farm reach a level of 8,000 to 9,000 gallons, the wastes are pumped to tank trucks for shipping to off-site treatment and reclamation facilities. The tanks are equipped with vertical multistage turbine type unloading pumps rated for 100 gallons per minute. The pumps are powered by 460-volt, 3-phase, totally enclosed vertical solid shaft, Class I, Group D motors. There is an unload pump for each individual waste tank mounted in the top of each tank. The pump controller switch locations are in the CDC Control Center and at the tank farm truck-loading station. Figure D-2-4 and D-2-7 (Appendix D) provides details of the tanker loading station. To ensure that hazardous wastes will not be stored for more than 1 year, the maximum waste volume stored in each tank within a 12-month period is turned over yearly.

Waste chemical piping in the tank farm is standard-weight black iron steel, ASTM A-53, Grade A, or Schedule 10 stainless steel with butt-welded joints.

5.6.5.2 Building 963 North Tank

The Building 963 tank is equipped with a vertical multistage turbine type unloading pump rated for 40 gallons per minute. The pump is powered by 480-volt, three-phase, totally enclosed vertical solid shaft, Class I, Group D motors. The pump is mounted in the tank top with the suction level extending to within 6 inches of the tank bottom. The remaining waste in the tank bottom is removed through the use of a vacuum truck or equivalent means. The operation of the pump is controlled by a power disconnect switch located by the tank pad. The tank is typically pumped out when it reaches 6,000 gallons. The waste is pumped to storage at the CDC. To ensure that hazardous wastes will not be stored for more than 1 year, the maximum waste volume stored in the tank within a 12-month period is turned over yearly.

5.6.5.3 CDC Container Storage Secondary Containment Tank

The CDC container storage secondary containment tank is equipped with a draw-off pipe that extends to within 3 inches of the tank bottom. The remaining waste in the tank bottom is removed through the use of a vacuum truck or equivalent means.

5.6.6 Secondary Containment

5.6.6.1 CDC Tank Farm

The waste tanks at the CDC tank farm are located in steel-lined, reinforced-concrete spill-containment basins. (See Figures D-2-6 and D-2-7, Appendix D, for details of the tank basins and spill control structures.) The basins are constructed of 3,000-pound-force per square inch gauge (psig) concrete lined with weathering steel. Each basin holds one or two tanks and provides a containment volume of 16,930 gallons.

Waste tanks are typically filled up to 9,000 gallons maximum prior to unloading. Thus a tank failure would typically result in a maximum of a 9,000-gallon spill, which would leave approximately 7,930 gallons in the containment basins for freeboard.

Run-on is prevented by a canopy roof that prevents the accumulation of precipitation in the secondary containment basins. Run-on is also prevented by basin walls which extend one foot above the surrounding area, the soil sloping away from the basins, and 6-inch sub drains. (Details of the secondary containment basins can be found in Figures D-2-6 and D-2-8 in Appendix D.)

The secondary containment basins are connected to a 74,052-gallon open-top reinforced-concrete spill-retention vault. For the layout of the containment basins and spill retention vault, see Figure D-2-7 in Appendix D. The spill retention vault is not considered part of the secondary containment system and is, therefore, not subject to Section 264.193 requirements. Instead, it provides tertiary containment that would be needed only in the event of flooding caused by the fire-prevention system.

5.6.6.2 Load/Unload Stations

The CDC tank farm load/unload station is contained in the trench system as shown on Figure D-2-7.

5.6.6.3 Building 963 North Tank

The Building 963 solvent waste tank is housed in an aboveground vault. The tank is situated within a steel-lined vault; thus, a tank failure would be contained by the vault. (See Figure D-2-2, Appendix D for details.)

The containment that the vault provides for the Building 963 tank is calculated as follows:

6.5 ft x 12.5 ft x 25.0 ft = 2,031.25 cubic feet

2,031.25 x 7.48 gallons/cubic foot = 15,193.75 gallons

Therefore the vault provides 168 percent of the volume of the tank.

The vault is equipped with a sump for spill collection and detection. A spill in the vault at Building 963 would be pumped by lowering a suction line into the sump. The suction line would be connected to a pump. The spill material would be transported for storage to the CDC tank farm or sent directly offsite for disposal.

# ATTACHMENT 5-1

# LATERAL MIGRATION TANK SYSTEM LEAKS

International Business Machines Corporation

Essex Junction, Vermont 05452
802/769-0111

August 23, 1990

Mr. John C. Miller
Hazardous Waste Management Program
Vermont Agency of Natural Resources
103 South Main Street
Waterbury, VT 05676

Dear Mr. Miller:

As you have discussed with Ray Mcintosh of IBM, Section 264.193 requires that secondary containment systems for tanks be able to contain the lateral as well as vertical migration of waste. IBM believes that the secondary containment system used at the tank storage facility will contain the lateral migration of wastes should a release occur.

Attached is a summary of the analysis ERM performed that demonstrates that the secondary containment for the IBM tank farm is able to contain the lateral migration of waste. Velocities of the waste stream from a leak were calculated to determine if a leak would travel outside of the secondary containment. The analysis showed that the maximum distance a waste stream could travel would be approximately 3.8 feet. The minimum distance from the secondary containment wall to the tank edge is five feet. Therefore, the secondary containment provides sufficient containment to prevent lateral migration of waste in the event of a leak occurring in the tanks.

I have included the engineering calculations associated with this determination as an attachment. If you have any questions on this, please feel free to call Ray Mcintosh at (802) 871-4272.

Sincerely yours,

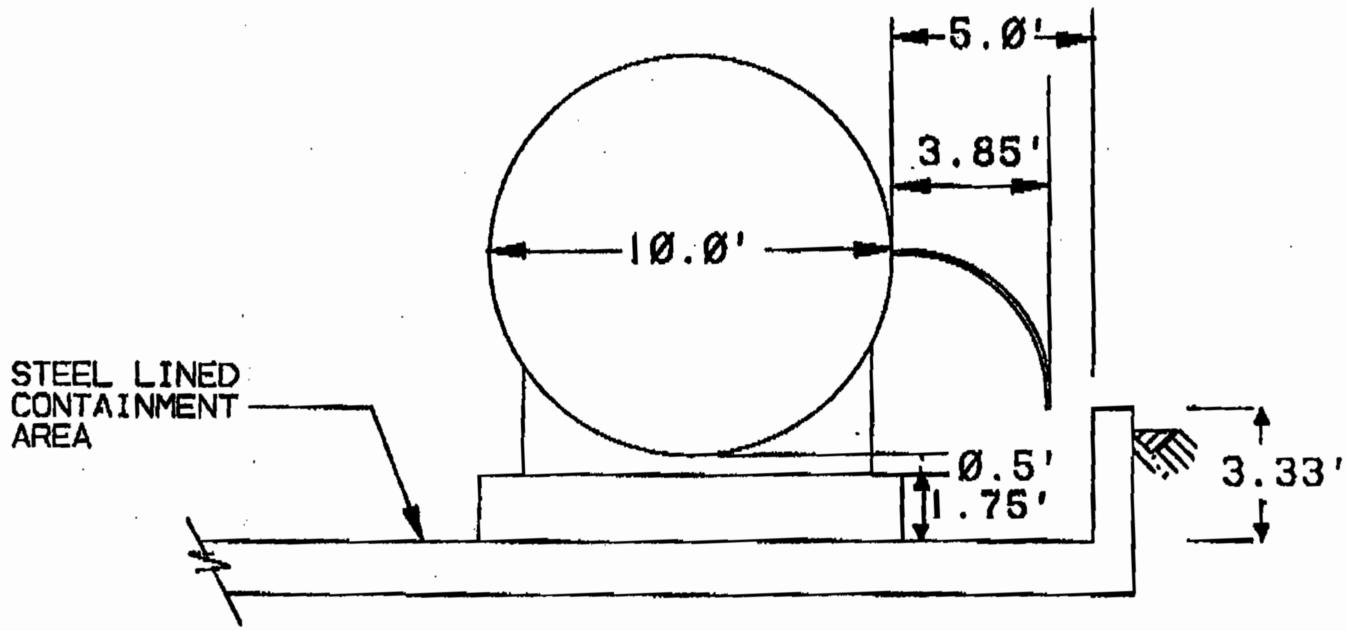
for D. Sargent

D. B. Sargent

DBS:bfb

ATTACHMENT

cc: J. Gallagher ERM




# TANK LEAK FLOW DIAGRAM

# ENGINEERING ANALYSIS OF LATERAL MIGRATION

The following engineering analysis was used to demonstrate that the secondary containment structures surrounding the waste tanks at the IBM tank farm will prevent the lateral migration of waste from the tanks in the event that a leak occurs. A worst-case scenario was used that assumed that a leak caused by would be a 1/4 inch diameter hole at the mid-point of the tank. The tanks are located in the secondary containment areas so the distance from the edge of the secondary containment structure to any tank is a minimum of five feet. The equation for flow through an orifice was used to approximate the flow from a leak in the tank wall.

The analysis was broken down into two parts. The first part determined the total time it would take a stream of waste to fall the distance from the leak to an elevation below the top of the secondary containment wall. This was calculated using the following formula:

$$d = 1/2at^2 + v_0t + d_0$$

where:

$d$ = distance to top of dike wall (ft) = 3'.33 ft
$v_0$ = initial downward velocity (ft/sec) = 0 ft/sec
$d_0$ = initial height of stream = 1.66' + 0.5' + 5' = 7.16'
$a$ = acceleration due to gravity = -32.2 ft/s$^2$
$t$ = time to fall from the leak to below the secondary containment wall

Rearranging this equation to solve for t:

$$t = ((7\ 16' - 3.33')/(32.2)(1/2))^{1/2} = (3.833*2/32.2)^{1/2}$$
$$t = 0.487 \text{ sec}$$

The second part of the analysis determined the velocity of fluid travelling through the 1/4" diameter hole in the tank wall. The following equation was used to describe the volumetric flow rate of the fluid leaving the tank:

$$q = 0.0438\,(d_o)^2\,C\,(h_L)^{1/2}$$ (Crane Co., "Flow of Fluids Through Valves Fittings and Pipe", 1965)

where:

$q$ = volumetric flow rate (cfs)
$d_o$ = orifice diameter (in.)
$C$ = flow coefficient = 0.6 (ave.)
$h_L$ = pressure drop across the orifice (ft of fluid)

This equation for q divided by the area, A, of the 1/4 inch diameter hole in the tank wall, gives the velocity, V, of the waste stream. This equation assumes that the density and viscosity of the fluid leaving the tank is approximately equal to water.

Since the maximum operating volume of the waste tanks is 9,000 gallons, the maximum level of liquid in the tanks will be 7.7'. This means that the maximum static head at the midpoint of the tank and the pressure drop across the orifice, $h_L$, will be:

7.7 ft - 5.0 ft = 2.7 ft

Therefore, the velocity, V, of the waste stream from the tanks will be:

$q = 0.0438\ (.25)^2\ 0.6\ (2.7)^{1/2}$
$q = 2.698 \times 10^{-3}$ cfs
A = area of 1/4" diameter orifice (sf) = $3.408 \times 10^{-4}$ sf
V = q/A = 7.91 ft/sec

This means that the total distance travelled by the stream when it is at the same elevation as the top of the dike wall is

7.91 ft/sec x 0.487 sec = 3.85 ft

Since the minimum distance from the edge of the dike wall to the edge of the tanks is 5' 0", a lateral leak will be contained within the secondary containment structure (see attached drawing).

# ATTACHMENT 5-2

# PAN-TYPE SECONDARY CONTAINMENT FOR PIPING

**ERM-New England, Inc.**

205 Portland Street • Boston, Massachusetts 02114 • (617) 742-8228

August 8, 1990

Mr. John C. Miller
Hazardous Waste Management Program
Vermont Agency of Natural Resources
103 South Main Street
Waterbury, Vermont 05676

Subj: IBM - Tank Farm Piping Secondary Containment

Dear Mr. Miller:

At the July 25, 1990 meeting held at IBM - Essex Junction on the recertification of IBM's RCRA permit, Ray McIntosh of IBM indicated that ERM would provide you with an explanation to show the adequacy of the pan-type secondary containment system used for the tank farm piping. This letter provides that explanation.

Regulatory Requirements

Auxiliary equipment, such as piping and pumps, associated with tank storage must have secondary containment (40 CFR 264.193(f)). The secondary containment must prevent any migration of wastes out of the system to the soil, ground water or surface water.

Secondary Containment Description and Hydraulic Analysis

Pipes within IBM's tank farm are secondarily contained by pans constructed under the pipes. The pans are made of welded stainless steel and are approximately seven feet, eight inches wide by six inches high. They are designed to contain spills or leaks from the tank farm piping and are sloped to drain and remove any liquids

A hydraulic analysis of the pans indicates that at the maximum flow rates supplied by the waste solvent transfer pumps (5 gpm), no wastes will escape over the sides of the pans prior to draining from the end of the pan into the secondary containment of the tanks. The analysis also showed that the flow that can be contained by the pans is greater than the flow that could be delivered by all of the waste solvent transfer pumps combined.

If you have any questions on this, please feel free to call me or Ray McIntosh at IBM.

Sincerely,

ERM-NEW ENGLAND, INC.

John W. Gallagher
Project Manager

JWG:nal:201-01

cc: Ray McIntosh, IBM

**ERM-New England, Inc.** 205 Portland Street • Boston, Massachusetts 02114 • (617) 742-8228

Project IBM W.O. No. Sheet of
Subject PAN FLOWS By Date
Chkd. by [illegible] Date 8/8/90

FOR FLOW $q = .0438\, d^2 \sqrt{\frac{h_L}{K_e + f\frac{L}{D}}}$

ASSUME MAX $L \approx 50$ ft

$q = 5$ gpm $= .668$ CFM $= .0111$ CFS

PANS ARE 6" HIGH BY $7\frac{2}{3}$' WIDE

ASSUME FLOW AT 1" HIGH

$d^2 = 4q/\pi$

$D = \sqrt{4A/\pi}$

$d^2 = 4 \times 7.66 \times .08 \times 144 / \pi = 112.3$

$D = (4 \times 7.66 \times .08/\pi)^{1/2} = .883$

ASSUME SHARP EDGED EXIT = $K = 1.0 = K_e$

HYD RADIUS $= .08 \times 7.66 / 7.66 + (.08 \times 2) = .0783$ ft

EQUIV DIAMETER $= d = 4 \times .0783 \times 12 = 3.75$ IN

RELATIVE ROUGHNESS $= \epsilon/D = .00017$

$\epsilon = .00015$ STEEL

$f = .013$

ASSUME LAMINAR FLOW

$$q = .0438 \times 112.3 \sqrt{\frac{.083}{1.0 + \frac{.013 \times 50}{.883}}}$$

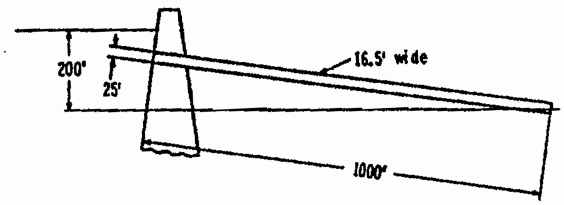
$q = 1.075$ CFS $= 482$ gpm

∴ FOR A FLUID IN THE PAN 1" THICK TRAVELLING FOR 50 ft IN THE PAN COULD HANDLE A FLOW OF 482 GPM.

# Application of Hydraulic Radius to Flow Problems

**Example 4-25...Rectangular Duct**

*Given:* A rectangular concrete overflow aqueduct, 25 feet high and 16.5 feet wide, has an absolute roughness ($\epsilon$) of 0.01 foot.




*Find:* The discharge rate in cubic feet per second when the liquid in the reservoir has reached the maximum height indicated in the above sketch. Assume the average temperature of the water is 60 F.

*Solution:*

1. $q = 0.0438\, d^2 \sqrt{\frac{h_L}{K_e + K_a}} = \sqrt{\frac{h_L}{K_e + f\frac{L}{D}}}$ ........page 3-4

where;

$K_e$ = resistance of entrance and exit

$K_a$ = resistance of aqueduct

To determine the flow rate, calculate the equivalent diameters for actual flow area.

$a = \frac{\pi d^2}{4}$, therefore, $d^2 = \frac{4a}{\pi}$

$A = \frac{\pi D^2}{4}$, therefore, $D = \sqrt{\frac{4A}{\pi}}$

To determine the friction factor from the Moody diagram, an equivalent diameter four times the hydraulic radius is used; refer to page 3-5.

$$\text{hydraulic radius} = \frac{\text{cross sectional flow area}}{\text{wetted perimeter}}$$

$R_e = 22\,700 \frac{q\rho}{d\mu}$ ............page 3-2

2. $d^2 = \frac{4a}{\pi} = \frac{4 \times 25 \times 16.5 \times 144}{\pi} = 75\,600$

3. $D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 25 \times 16.5}{\pi}} = 22.9$

4. Assuming a sharp edged entrance,

$K = 0.5$ ..........page A-26

Assuming a sharp edged exit to atmosphere,

$K = 1.0$ ..........page A-26

Then, resistance of entrance and exit,

$K_e = 1.0 + 0.5 = 1.5$

5. Hydraulic radius $= \frac{16.5 \times 25}{2\,(16.5 + 25)} = 4.97$ ft

6. Equivalent diameter, $d = 4 \times 4.97 \times 12$

$d = 239$ in.

7. Relative roughness, $\epsilon/D = 0.0005$ ..page A-23

8. $f = 0.017$ ................{fully turbulent flow assumed; page A-23

9. $q = 0.0438 \times 75\,600 \sqrt{\frac{200}{1.5 + \frac{0.017 \times 1000}{22.9}}}$

$q = 31\,300$

10. Calculate $R_e$ and check, $f = 0.017$ for 31 300 cfs flow.

11. $\rho = 62.34$ ............page A-6

12. $\mu = 1.1$ ............page A-3

13. $R_e = \frac{22\,700 \times 31\,300 \times 62.34}{239 \times 1.1}$

$R_e = 168\,400\,000$ or $1.684 \times 10^8$

14. $f = 0.017$ ......for calculated $R_e$; page A-24

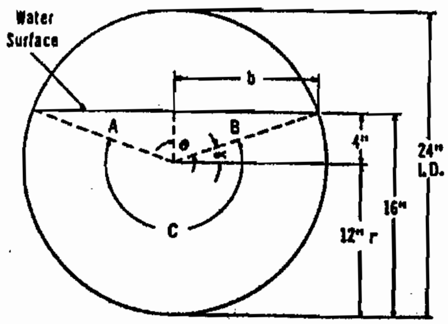
15. Since the friction factor assumed in Step *8* and that determined in Step *14* are in agreement, the discharge flow will be **31 300 cfs.**

16. If the assumed friction factor and the friction factor based on the calculated Reynolds number were not in reasonable agreement, the former should be adjusted and calculations repeated until reasonable agreement is reached.

## Application of Hydraulic Radius to Flow Problems — continued

**Example 4-26 . . . Pipe Partially Filled With Flowing Water**

*Given:* A cast iron water pipe is two-thirds full of flowing water (60 F). The pipe has an inside diameter of 24 inches and a slope of ¾-inch per foot. Note the sketch that follows.




*Find:* The flow rate in gallons per minute.

*Solution:*

1. $Q = 19.65\, d^2 \sqrt{\frac{h_L D}{f L}}$ . . . . . . . . . . . . . page 3-4

To determine the flow rate in a partially full pipe, calculate the equivalent pipe diameters for the actual flow area.

$$a = \frac{\pi d^2}{4}, \text{ therefore, } d^2 = \frac{4a}{\pi}$$

$$A = \frac{\pi D^2}{4}, \text{ therefore, } D = \sqrt{\frac{4A}{\pi}}$$

To determine the friction factor from the Moody diagram, an equivalent diameter four times the hydraulic radius is used; refer to page 3-5.

$$\text{hydraulic radius} = \frac{\text{cross sectional flow area}}{\text{wetted perimeter}}$$

$R_e = 50.6 \frac{Q\rho}{d\mu}$ . . . . . . . . . . . page 3-2 or 3-8

2. Depth of flowing water equals:

$$\frac{2}{3}(24) = 16 \text{ in.}$$

3. $\text{Cos } \theta = \frac{4}{r} = \frac{4}{12} = 0.333$

$\theta = 70°32'$

$\alpha = 90° - 70°32' = 19°28' = 19.47°$

4. $\text{Area C} = \frac{\pi d^2}{4}\left[\frac{180 + (2 \times 19.47)}{360}\right]$

$\text{Area C} = \frac{\pi 24^2}{4}\left(\frac{218.94}{360}\right) = 275 \text{ in}^2$

5. $b = \sqrt{r^2 - 4^2} = \sqrt{12^2 - 16} = 11.31 \text{ in.}$

6. $\text{Area A} = \text{Area B} = \frac{1}{2}(4\text{b}) = \frac{1}{2}(4 \times 11.31)$

$\text{Area A or B} = 22.6 \text{ in}^2$

7. The cross sectional area of flow equals:

$\text{A} + \text{B} + \text{C} = 22.6 + 22.6 + 275$

$= 320.2 \text{ in}^2$

8. $d^2 = \frac{4a}{\pi} = \frac{4 \times 320.2}{\pi} = 408$

$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 320.2}{\pi \times 144}} = 1.683$

9. $h_L = \Delta h = \frac{0.75}{12} = 0.0625$ ft per ft

10. The wetted perimeter equals:

$\pi d \left(\frac{218.94}{360}\right)$

or, $\pi\, 24 \left(\frac{218.94}{360}\right) = 45.9$ in.

11. Hydraulic radius $= \frac{320.2}{45.9} = 6.98$ in.

12. Equivalent diameter $d = 4 \times 6.98 = 27.92$ in.

13. Relative roughness $\frac{\epsilon}{D} = 0.000\,36$ . . . . page A-23

14. $f = 0.0155$ . . . . . . . . . . . {assuming fully turbulent flow; page A-23

15. $Q = 19.65 \times 408 \sqrt{\frac{0.0625 \times 1.683}{0.0155 \times 1}}$

$Q = 20\,900$

16. Calculate the Reynolds number to check the friction factor assumed in Step 14.

17. $\rho = 62.34$ . . . . . . . . . . . . . . . . . . . . . page A-6

18. $\mu = 1.1$ . . . . . . . . . . . . . . . . . . . . . page A-3

19. $R_e = \frac{50.6 \times 20\,900 \times 62.34}{27.92 \times 1.1}$

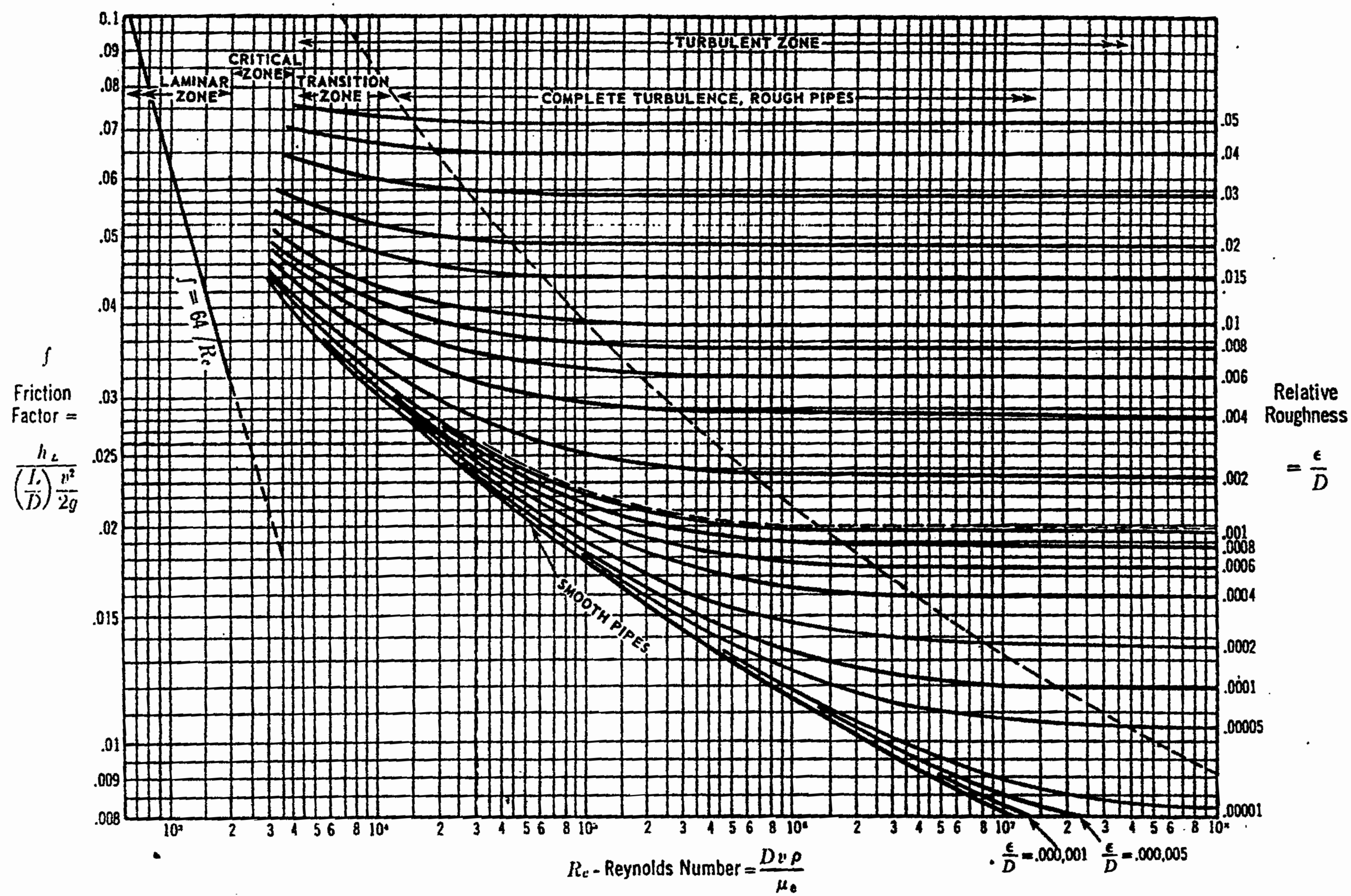
$R_e = 2\,150\,000 \text{ or } 2.15 \times 10^6$

20. $f = 0.0155$ . . . . . . . . . . . . . . . . . . . . . page A-24

21. Since the friction factor assumed in Step 14 and that determined in Step 20 are in agreement, the flow rate will be 20 900 gpm.

22. If the assumed friction factor, and the friction factor based on the calculated Reynolds number, were not in reasonable agreement, the former should be adjusted and the calculations repeated until reasonable agreement is reached.

# Friction Factors for Any Type of Commercial Pipe[18]




Problem:
Determine the friction factor for 10-inch cast iron pipe (10.16" I.D.) at a Reynolds number flow of 30,000.

Solution: The relative roughness (see page A-23) is 0.001. Then, the friction factor ($f$) equals 0.026.

*For other forms of the $R_e$ equation, see page 3-2.*

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