Data Requirements for Simulation of Hydrogeologic Effects of Liquid Waste Injection, Harrison and Jackson Counties, Mississippi

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 94-4021

Prepared in cooperation with the
MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY,
OFFICE OF POLLUTION CONTROL

U.S. DEPARTMENT OF THE INTERIOR
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Jackson, Mississippi
1994

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CONVERSION FACTORS AND ABBREVIATED UNITS

Multiply	By	To obtain
foot (ft)	0.3048	meter
cubic foot (ft^3)	2.832×10^{-2}	cubic meter
mile (mi)	1.609	kilometer
British thermal unit (BTU)	1.055×10^{-3}	Joule
milligram per liter (mg/L)	8.345	pound per million gallons
foot per day (ft/d)	0.3048	meter per day
centipoise (cP)	0.672	pound per foot per second
pound per square inch (lb/in^2)	6.895	kiloNewton per square meter
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter
gram per cubic centimeter (g/cm^3)	62.55	pound per cubic foot
millidarcy (md)	1.06×10^{-14}	square foot
darcy	1.06×10^{-11}	square foot

Temperatures may be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) with the following formulas:

$$°C = (°F - 32) / 1.8$$
$$°F = 1.8 (°C) + 32$$

DATA REQUIREMENTS FOR SIMULATION OF HYDROGEOLOGIC EFFECTS OF LIQUID WASTE INJECTION, HARRISON AND JACKSON COUNTIES, MISSISSIPPI

by Richard A. Rebich

ABSTRACT

Available literature and data were reviewed to quantify data requirements for computer simulation of hydrogeologic effects of liquid waste injection in southeastern Mississippi. Emphasis of each review was placed on quantifying physical properties of current Class I injection zones in Harrison and Jackson Counties. Class I injection zones are zones that are used for injection of hazardous or non-hazardous liquid waste below a formation containing the lowermost underground source of drinking water located within one-quarter of a mile of the injection well.

Several mathematical models have been developed to simulate injection effects. The Basic Plume Method was selected because it is commonly used in permit applications, and the Intercomp model was selected because it is generally accepted and used in injection-related research. The input data requirements of the two models were combined into a single data requirement list inclusive of physical properties of injection zones only; injected waste and well properties are not included because such information is site-specific by industry, which is beyond the scope of this report.

Results of the reviews of available literature and data indicated that Class I permit applications and standard-reference chemistry and physics texts were the primary sources of information to quantify physical properties of injection zones in Harrison and Jackson Counties. With the exception of a few reports and supplementary data for one injection zone in Jackson County, very little additional information pertaining to physical properties of the injection zones was available in sources other than permit applications and standard-reference texts.

INTRODUCTION

Underground injection of industrial waste is a disposal process in which liquid waste is injected and stored beneath the surface of the earth. Underground injection methods were developed by the petroleum industry in the 1930's for disposal of liquid wastes such as brines from oil and gas production. Since then, other industries have used underground injection to dispose of wastewater that is impractical or uneconomical to treat for surface-water discharge. Advantages of underground injection include eliminating a wastewater to be discharged into surface waters; eliminating the need for land-consuming treatment facilities; and decreasing energy consumption by eliminating treatment facilities.

Class I injection wells are defined as wells used to inject hazardous or non-hazardous liquid waste below a formation containing the lowermost underground source of drinking water (USDW) located within one-quarter of a mile of the well bore (U.S. Environmental Protection Agency, 1990, p. 683). The area of review surrounding a Class I well is composed of the injection zone, the confining units, and the formation fluids. The injection zone is required to have sufficient thickness and adequate porosity and permeability to accept the injected waste. The confining units are required to have large areal extent to contain the injected waste from upward or downward migration. The formation fluids are required to have a dissolved-solids concentration greater than 10,000 mg/L, have negligible commercial value, and be chemically compatible with the injected fluids.

Methods used to evaluate the area of review of a Class I injection site include collection of comprehensive site data, identification of potential hydrogeologic problems, and injection simulation using computer models. Data-collection techniques include geophysical logs, which are used to evaluate geologic strata, waste movement, and the structural integrity of the injection well; and core tests, which include whole core, sidewall core, and formation fluid samples to identify hydraulic and physical properties in the injection zone. After data collection, potential hydrogeologic problems such as chemical compatibility between the injected waste and injection zone materials, abandoned wells, seismic activity, and subsurface migration of the injected waste out of the injection zone may then be identified in the area of review. Computer models can be used to simulate the effects of injection and to evaluate the potential problems over time.

For this report, available literature and data were reviewed to quantify data requirements for computer simulation of hydrogeologic effects of liquid waste injection in southeastern Mississippi. Emphasis of each review was placed on quantifying physical properties of current Class I injection zones in Harrison and Jackson Counties. Specific computer models considered for this report were the Basic Plume Method (Miller and others, 1986) and the Intercomp model (Intera, 1978). The reviews were conducted and this report was prepared by the U.S. Geological Survey (USGS) in cooperation with the Office of Pollution Control (OPC) of the Mississippi Department of Environmental Quality, which regulates and issues permits for underground injection operations in Mississippi. Information from this report will be useful to the OPC in making decisions concerning Class I injection sites in Mississippi.

DESCRIPTION OF STUDY AREA

Mississippi currently (1994) has three Class I injection sites containing a total of six wells. Hazardous waste is injected into three wells in Harrison County and two wells in Jackson County; both counties are in southeastern Mississippi (fig. 1) bordering the Gulf of Mexico. Non-hazardous waste is injected into one well in Hinds County in central Mississippi (fig. 1). For this report, available literature and data were reviewed to quantify physical properties of injection zones at the two hazardous waste sites in southeastern Mississippi only. Brief descriptions of the two site locations and injection zones are presented in the following paragraphs.

Three Class I wells are completed in undifferentiated sandy sediments of Early Cretaceous age in southern Harrison County. This injection zone is sometimes referred to as the Washita-Fredricksburg injection zone (table 1) by petroleum industries in Arkansas, Louisiana, and Texas, and will be referred to as such throughout the remainder of this report. The injection zone is located approximately 9,800 to 10,000 ft below land surface (State of Mississippi, 1990). Locally, a 170-ft thick confining unit separates the overlying Tuscaloosa aquifer system from the injection zone (table 1).

Two Class I wells are completed in different injection zones in southern Jackson County. The first well is completed approximately 3,950 ft below land surface in the Wilcox Group, upper part of the Meridian-upper Wilcox aquifer (table 1). The Wilcox Group, upper part, injection zone is referred to as the upper Wilcox injection zone throughout the remainder of this report. This injection zone is composed of sandstone containing saltwater with a dissolved-solids concentration greater than 10,000 mg/L. Freshwater does not occur in the upper Wilcox aquifer at this location; the downdip limit of freshwater occurs approximately 100 mi north (Wasson, 1986). The injection zone is overlain by confining units approximately 160 ft thick composed of shales of the Claiborne Group (Basic City Shale Member, table 1).

The second well is completed in a zone approximately 2,500 ft below the surface in the Hattiesburg Formation of the Miocene aquifer system (table 1). This injection zone will be referred to as the Miocene injection zone throughout the remainder of this report.

The Miocene aquifer system is composed of clay, silt, sand, sandstone, and gravel, and may have beds of limestone at depth. In southern Jackson County, the top of the Miocene sediments is at a depth of about 500 ft, and the base of the Miocene sediments is at a depth of about 3,400 ft (Sumner and others, 1989). The base of freshwater within the Miocene aquifer system is at a depth of about 1,000 ft (Sumner and others, 1989).

The Miocene injection zone in the Hattiesburg Formation is composed primarily of sandstone and is considered to lie between depths of 2,450 and 2,700 ft (State of Mississippi, 1989). Although regional dissolved-solids concentrations average nearly 10,000 mg/L in the Miocene aquifer system (Sumner and others, 1989), dissolved-solids concentrations are estimated to be about 30,000 mg/L in the Miocene injection zone at this location (State of Mississippi, 1989).

In contrast to older geologic units along the gulf coast, the sediments composing the Miocene aquifer "lack regional lithologic layering and tend to be areally discontinuous and variable in thickness" (Sumner and others, 1989, p. 3). The lack of lithologic layering indicates that adequate, regionally extensive confining units may not exist for injection purposes; however,

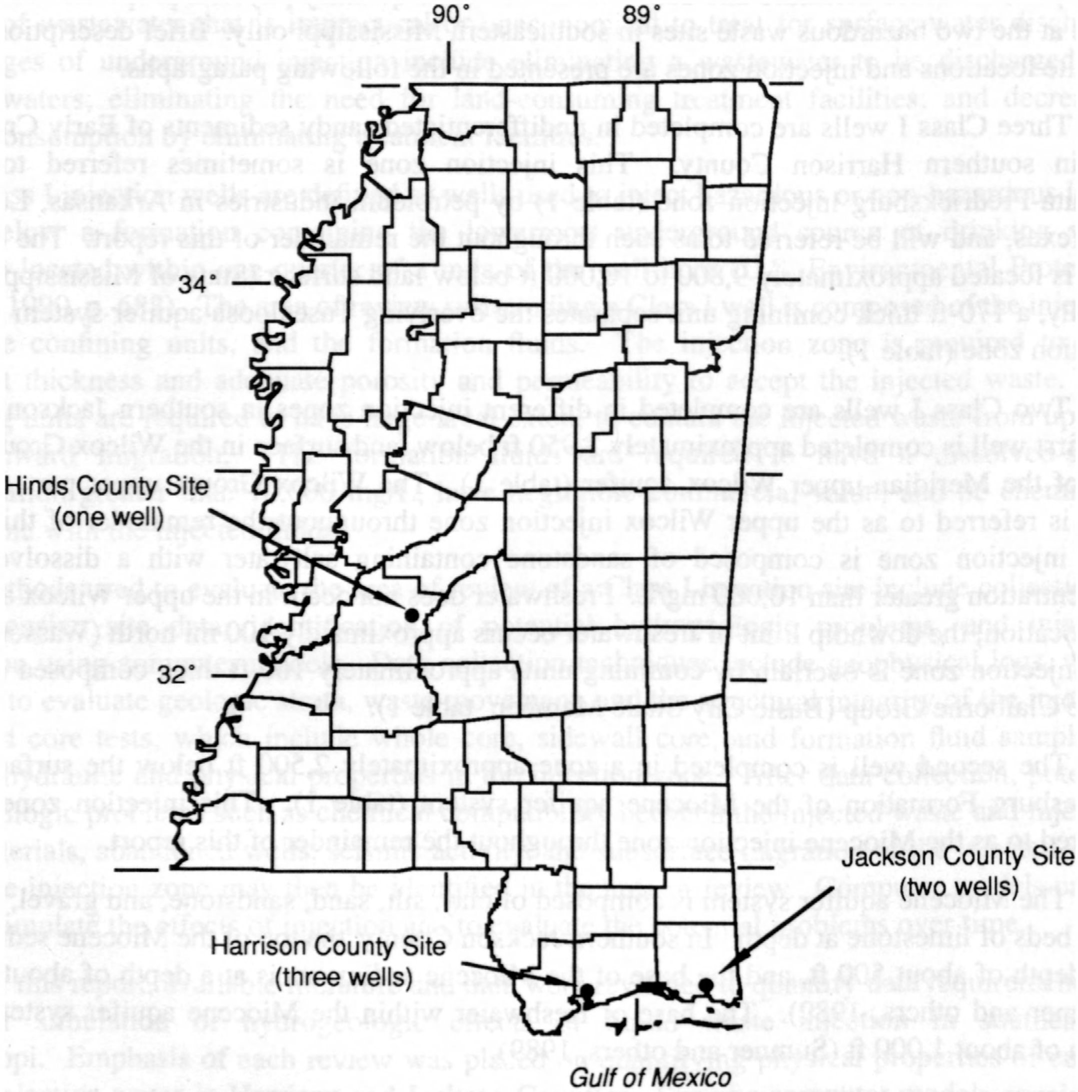

Figure 1. Class I injection well locations in Mississippi.

Table 1. -- Geologic units and principal aquifers in Mississippi [modified from Slack and Darden, 1991, p. 21]

Erathem	System	Series	Group	Geologic unit	Principal aquifer or aquifer system
				Quaternary alluvium	
	Quaternary	Holocene and Pleistocene		Mississippi River valley alluvium	Mississippi River alluvial aquifer
		Pleistocene		Loess	
				Terrace deposits	
		Pliocene		Citronelle Formation	Citronelle aquifer
				Graham Ferry Formation	
				Pascagoula Formation	
				Hattiesburg Formation (3)	
		Miocene		Catahoula Sandstone, upper part	Miocene aquifer system
				Catahoula Sandstone, lower part	
				Deposits of Miocene age	
				Bacutunna Formation	
				Waynesboro sand lentil	
				Byram Formation	
				Glendon Limestone	
		Oligocene	Vicksburg Group	Marianna Formation	Oligocene aquifer system
				Mint Spring Formation	
	Tertiary			Forest Hill Formation	
				Yazoo Clay	
			Jackson Group	Moodys Branch Formation	
				Cockfield Formation	Cockfield aquifer
Cenozoic				Cook Mountain Formation	
				Sparta Sand	Sparta aquifer
				Zilpha Clay	
		Eocene		Winona Sand	
			Claiborne Group	Tallahatta Formation	Winona-Tallahatta aquifer
				Neshoba Sand Member	
				Basic City Shale Member	
				Meridian Sand Member	
				Meridian Sand Member	
				Wilcox Group, upper part (2)	Meridian-upper Wilcox aquifer
				Hatchetigbee Formation	
			Wilcox Group	Tuscahoma Formation	
				Wilcox Group, middle part	
				Nanafalia Formation	
		Paleocene		Fearn Springs Member	Lower Wilcox aquifer
				Wilcox Group, lower part	
				Naheola Formation	
			Midway Group	Porters Creek Clay	
				Matthews Landing Marl Member	
				Clayton Formation	
				Prairie Bluff Chalk and Owl Creek Formation	
				Ripley Formation	Ripley aquifer
			Selma Group	Demopolis Chalk	
				Coffee Sand	Coffee Sand aquifer
				Mooreville Chalk	
				Arcola Limestone Member	
Mesozoic		Upper Cretaceous		Eutaw Formation	
	Cretaceous			Tombigbee Sand Member	
				Eutaw Formation, lower part	Eutaw-McShan aquifer
			Tuscaloosa Group	McShan Formation	
				Gordo Formation	
				Coker Formation	Tuscaloosa aquifer system
				Massive sand	
		Lower Cretaceous		Undifferentiated (1)	
Paleozoic				Undifferentiated	Paleozoic aquifer system
				Paleozoic Erathem	

(1) Includes Washita-Fredricksburg injection zone (2) Includes upper Wilcox injection zone (3) Includes Miocene injection zone

small-scale layering due to lenticular formations of clay or shale may form confining units. In fact, more than 220 ft of confining shale overlies the injection zone at this location at a depth of about 2,200 ft (State of Mississippi, 1989).

The industry operating in southern Jackson County recently (1992) petitioned State regulatory agencies to cease operations at the second well completed in the Miocene aquifer. A new well similar to the first well has been drilled and is completed in the upper Wilcox injection zone. Injection operations using the new well began before the end of calendar year 1993.

DATA REQUIREMENTS FOR SIMULATION OF HYDROGEOLOGIC EFFECTS OF INJECTION

Computer models can be used to evaluate a potential Class I injection site by simulating hydrogeologic effects of injection over time. Most models that simulate injection effects are based on the combination of theories of ground-water pressure and flow with ground-water transport. Both pressure and flow would ideally follow a cylindrical pattern outward from an injection well. However, because of transient conditions in the injection zone, such as density differences and temperature variations, both pressure and flow patterns vary considerably throughout the thickness of the injection zone.

Several computer models are available to simulate hydrogeologic effects of injection. Specifically, these models estimate the short and long-term effects of injection in the subsurface environment, such as the extent of both vertical and lateral waste movement, pressure responses, and energy transfer. Two computer models capable of simulating the effects of injection that were selected for evaluation in this report are the Basic Plume Method and the Intercomp model. The Basic Plume Method was selected because it is commonly used in injection permit applications, and the Intercomp model was selected because it is generally accepted and used in injection-related research.

The following sections include a brief description and listing of the general input data requirements for the two selected models. The input data requirements for the two models are then compared and combined into a single data requirement list. Subsequent sections of the report describe results of reviews of journal articles, reference publications, and available data bases that were conducted to quantify physical properties of injection zones in Jackson and Harrison Counties.

Data Requirement Listings

The first two segments in this section include a brief introduction and a listing and description of the general input data requirements for the Basic Plume Method and the Intercomp model. The input data requirements for the two models are summarized from their respective references. The third segment includes a brief explanation of how the data requirements for the two computer models were combined and a listing of the combined data requirements.

Basic Plume Method

The Basic Plume Method is a series of numerical models developed by the chemical industry to estimate horizontal and vertical movement of injected waste (Miller and others, 1986). The method is based on similar techniques developed by the petroleum industry, which used numerical methods to simulate hydrogeologic processes at sites where injection wells enhance oil production (Chester Miller, E.I. DuPont de Nemours and Co., Inc., oral commun., 1992). The method is not intended to estimate the exact waste front location, but rather to estimate where the waste front will **not** be located. For the purposes of this report, the overall method is named the Basic Plume Method after the Basic Plume Model, which estimates horizontal movement as part of the overall method. The Basic Plume Method is composed of six models: the Basic Plume and 10,000-Year Waste Plume Models, which are used to estimate horizontal waste movement; and the Multilayer Vertical-Permeation, Molecular Diffusion, Multilayer Pressure, and Flow Resistance Models, which are used to estimate vertical waste movement.

Input data requirements for the Basic Plume Method can be divided into four general categories: hydrogeologic properties, fluid properties, molecular diffusion properties, and operating properties. Specific data requirements within these categories and the models they may affect are presented as follows (modified from State of Mississippi, 1990):

A. Hydrogeologic Properties -

1. Layer Thickness - Layers defined for the model do not necessarily coincide with the formal layering of the stratigraphic column; rather, layers are specified according to their behavior as functional hydrogeologic units. The models are developed based on the use of uniform layer thickness.

2. Layer Permeabilities - Injection zone permeability data are primary input properties for the Basic Plume, 10,000-Year Waste Plume, and Multilayer Pressure Models, and confining unit permeability data are primary input properties for the Multilayer Vertical Permeation Model.

3. Layer Porosities - Injection zone porosity data are minor input properties for the Basic Plume and 10,000-Year Waste Plume Models, but confining unit porosity data are primary input properties for the Multilayer Vertical Permeation and Molecular Diffusion Models.

4. Layer Compressibilities - Injection zone and confining unit compressibility data are minor input properties to the various models.

B. Fluid Properties -

1. Viscosity - Formation fluid and injected waste viscosity data are used in the various models of the method. In addition, temperature measurements are important for viscosity calculations.

2. Density - The density of the formation fluid and the injected waste are primary input properties for the 10,000-Year Waste Plume Model.

3. Fluid Compressibility - Formation and injected waste fluid compressibility are minor input properties to the Multilayer Pressure Model.

4. Formation Pressure - Injection zone formation pressure are essential during pressure calibration of the model.

C. Molecular Diffusion Properties -

1. Required Concentration Reductions - This parameter is a fractional coefficient that reduces a contaminant species to be non-hazardous. These reductions are defined as the health-based standard values (U.S. Environmental Protection Agency, 1986) of the contaminant divided by the concentrations in the waste stream.

2. Molecular Diffusion Coefficients - Diffusion coefficients of key contaminants in the injected waste are experimentally determined for free aqueous solutions. These coefficients are then corrected using a Geometric Correction Factor, which is based on lithology and porosity, to determine an effective diffusion coefficient for the confining unit.

D. Operating Properties - The Basic Plume Method requires the location and completion zones of all injection and monitor wells, the monthly and yearly injection history for each well, the record of monitor well pressures, and injection rates.

Intercomp Model

The Intercomp Model was developed by Intercomp Resource Development and Engineering, Inc. (1976) and published under contract with the USGS. This model was later revised and appended by Intera Environmental Consultants, Inc. (1978). The initial model has been nicknamed "SWIP" in many publications, which stands for Subsurface Waste Injection Program (Merritt, 1984). The model provides a three-dimensional transient simulation of waste injection in the subsurface environment by solving for specific fluid properties or flow patterns in terms of pressure, temperature, and waste concentration. The results of the model simulations can then be interpreted with respect to regional ground-water flow patterns.

The Intercomp model actually is a combination of two separate submodels: a reservoir submodel, which can be solved for flow and energy transport in the injection zone and adjacent confining units; and a well-bore submodel, which can be solved for flow and energy transport for vertical flows in the injection well. By utilizing these two submodels, simulations can include nonuniformities in the flow system such as physical displacements (stratified permeabilities) and flow variations (variable densities which can form convective cells).

Input data requirements for the Intercomp model can be divided into two general categories: fluid and aquifer properties data and well data. Specific data requirements within these two categories are presented as follows:

A. Fluid and Aquifer Properties - These data generally are expressed as functions of pressure, temperature, and concentration. However, these data may be assumed constant or expressed in terms of other constant properties.

1. Compressibility - Fluid compressibility is required and is entered at the reference pressure and temperature. The reference pressure is the initial pressure at a user-specified reference depth such as the top of the injection zone. The reference temperature is used to calculate fluid density and internal energy. Rock compressibility is required and is entered as an average value over the expected range of pressure and temperature.

2. Thermal Expansion Factor - This factor is used to calculate fluid density when necessary and is specified at the reference pressure and temperature.

3. Heat Capacities - "Total" heat capacity is the heat required to raise the fluid and injection zone material temperatures one degree Fahrenheit. Heat capacity is a function of temperature and pressure but is assumed to be constant in the reservoir submodel calculations.

4. Fluid Density - Injected waste and formation fluid densities are entered at the same pressure and temperature conditions.

5. Fluid Viscosity - The model requires as much viscosity information as available. Injected waste and formation fluid viscosities may be entered as functions of temperature. Also, a reference viscosity may be entered as a function of concentration at a reference temperature. If any fluid viscosity is to be independent of temperature, then the same value of viscosity is entered at two temperatures.

6. Dispersivity - Various dispersivity values and coefficients are calculated based on values of longitudinal and transverse dispersivities, thermal conductivity, and molecular diffusivity values for the injection zone. Longitudinal and transverse dispersivity are required for the model to calculate nine dispersion coefficients. Thermal conductivities are required for the porous injection zone, and a value for molecular diffusivity is required representing a net value to include the effects of porosity and tortuosity.

7. Transmission Coefficients - Fluid velocity in the reservoir submodel are expressed in terms of spatial pressure gradients by means of Darcy's Law for flow in porous media. The transmission coefficient is the hydraulic conductivity and is entered at reference conditions. Permeability (in units of darcies) is calculated based on hydraulic conductivity and is assumed to be constant in the injection zone.

8. Intera Revision - When the Intercomp model was revised by Intera in 1978, the revision included several input data requirement updates. For example, water-table conditions may be entered if the solution of the energy equation is not desired; vertical recharge rates may be entered for the uppermost layer of the modeled system where recharge occurs; and initial temperatures may be entered on a regional basis for the modeled system.

B. Well Data - Model requirements include entering a well index, which is used to calculate the pressure drop between the well-bore and the grid block center. If well-bore calculations are not conducted, then bottom-hole conditions are specified. If well-bore calculations are to be performed, then the well-head conditions and well specifications are specified including well depth, internal diameter of the tubing inside of the well, outer diameter of the casing, inner tubing roughness, and the overall heat transfer coefficient between the fluid inside the tubing and the outside surface of the casing.

Combined Physical Property Requirement List

The input data requirements for the Basic Plume Method and the Intercomp model were compared and combined to form a single data requirement list. This list is inclusive for physical properties of an injection zone only; injected waste and well properties are not included because such information is site-specific by industry, which is beyond the scope of this report. The combined physical property requirement list can be divided into two sections: physical property requirements similar to both models and physical property requirements unique to the Intercomp model. The combined list is presented along with the appropriate units of measure as they appear in the respective model documentations as follows:

A. Physical property requirements similar to both models.

1. Hydrogeologic properties -

   a. Injection zone and confining unit permeability data.
   Units = darcies [or millidarcies (md)]

   b. Injection zone and confining unit porosity data.
   Units = percent

   c. Injection zone and confining unit compressibility data.
   Units = 1/pound per square inch [$1/(lb/in^2)$]

   d. Injection zone pressure and temperature data.
   Pressure units = pound per square inch (lb/in^2)
   Temperature units = degrees Fahrenheit (°F)

2. Formation fluid properties -

   a. Viscosity data.
   Units = centipoise (cP)

   b. Density data.
   Units = pound per cubic foot (lb/ft^3)

   c. Compressibility data.
   Units = 1/pound per square inch [$1/(lb/in^2)$]

B. Physical property requirements unique to the Intercomp model.

1. Reference temperature and pressure for user-specified reference depths.
   Temperature units = degrees Fahrenheit (°F)
   Pressure units = pound per square inch (lb/in^2)

2. Thermal expansion factor.
   Units = 1/ degrees Fahrenheit (1/°F)

3. Heat capacity of formation fluid and injection zone material.

Formation fluid heat capacity units = British thermal unit per pound per degree Fahrenheit = BTU/lb-°F

Injection zone material heat capacity units = British thermal unit per cubic foot per degree Fahrenheit = BTU/ft^3-°F

4. Injection zone longitudinal dispersivity, transverse dispersivity, and thermal conductivity.

Longitudinal and transverse dispersivity units = feet (ft)

Thermal conductivity units = British thermal unit per foot per day per degree Fahrenheit = BTU/ft-day-°F

5. Hydraulic conductivity.

Units = cubic foot per day per square foot [(ft^3/day)/ft^2], which reduces to foot per day (ft/day)

Harrison County Injection Site

This section includes the results of reviews of available literature and data conducted to quantify physical properties for the Washita-Fredricksburg injection zone located approximately 9,800 to 10,000 ft below land surface in Harrison County. Physical properties for this injection zone were quantified with respect to the combined physical property requirement list previously presented. Permit applications of industries petitioning to operate Class I injection wells and standard-reference chemistry and physics texts were the primary sources of information for the reviews. Very little additional information pertaining to physical properties for this particular injection zone was available in sources other than permit applications and standard-reference texts. The physical properties quantified for the Washita-Fredricksburg injection zone in Harrison County are summarized in table 2 along with their respective references.

For clarity, some additional discussion of selected physical properties for the Washita-Fredricksburg injection zone in Harrison County is included as follows:

- For production fields in southwestern Alabama, Bolin and others (1989) state that permeability of Cretaceous material ranges from 61 to 500 md, porosity ranges from 10 to 31 percent, and bottom-hole pressures range from 2,600 to 5,100 lb/in^2
- The formation fluid viscosity is defined in terms of observed variations in temperature and dissolved-solids concentration with depth. Viscosity ranges from 0.41 to 0.42 cP between depths of 9,000 to 10,000 ft (State of Mississippi, 1990).

Table 2. -- *Physical properties of the Washita-Fredricksburg injection zone in Harrison County*

[md, millidarcy; lb/in², pound per square inch; ft, foot; °F, degree Fahrenheit; cP, centipoise; lb/ft³, pound per cubic foot; BTU/lb-°F, British thermal unit per pound per degree Fahrenheit; BTU/ft³-°F, British thermal unit per cubic foot per degree Fahrenheit; BTU/ft-day-°F, British thermal unit per foot per day per degree Fahrenheit; ft/day, foot per day]

Physical property	Representative value or range of values	Reference
	Physical property requirements similar to both models	
Hydrogeologic properties -		
Permeability		
Injection zone	363 md	State of Mississippi, 1990
	61-500 md	Bolin and others, 1989
Confining unit	6.2×10^{-8} md *	State of Mississippi, 1990
Porosity		
Injection zone	24 percent	State of Mississippi, 1990
	10-31 percent	Bolin and others, 1989
Confining unit	20 percent *	Dickinson, 1953
Compressibility		
Injection zone	7×10^{-6} / (lb/in²) *	Freeze and Cherry, 1979; Neuzil, 1986
	2.6×10^{-6} / (lb/in²) *	Prats, 1986
Confining unit	7×10^{-5} / (lb/in²) *	Freeze and Cherry, 1979; Neuzil, 1986
Injection zone pressure	4,500 lb/in² at 9,850 ft	State of Mississippi, 1990
	2,600-5,100 lb/in² **	Bolin and others, 1989
Injection zone temperature	215 °F at 9,900 ft	State of Mississippi, 1990
Formation fluid properties -		
Formation fluid viscosity	0.41 to 0.42 cP (between depths of 9,000 and 10,000 ft)	State of Mississippi, 1990
Formation fluid density	66.9 lb/ft³	State of Mississippi, 1990
Formation fluid compressibility	3×10^{-6} / (lb/in²) *	Freeze and Cherry, 1979; Prats, 1986
	Physical property requirements unique to Intercomp model	
Reference temperature (top of injection zone)	194 °F at 9,780 ft	State of Mississippi, 1990
Reference pressure (top of injection zone)	4,600 lb/in² at 9,780 ft	State of Mississippi, 1990
Thermal expansion factor	0.0002/°F *	Intercomp, 1976
	0.00047/°F *	Prats, 1986
Heat capacity		
Formation fluid	1 BTU/lb-°F *	Intercomp, 1976; Prats, 1986
Injection zone material	30 BTU/ft³-°F *	Intercomp, 1976
	39 BTU/ft³-°F *	Prats, 1986
Longitudinal dispersivity	50 ft *	State of Mississippi, 1990
Transverse dispersivity	5 ft *	State of Mississippi, 1990
Thermal conductivity	28 BTU/ft-day-°F *	State of Mississippi, 1990
	16 BTU/ft-day-°F *	Prats, 1986
Hydraulic conductivity	2.6 ft/day *	Freeze and Cherry, 1979

* estimated or computed

** bottom-hole pressures

- Formation fluid density is determined from temperature and dissolved-solids concentration data. The density of the formation fluid containing a dissolved-solids concentration of 155,000 mg/L at a formation fluid temperature of 210 °F is estimated to be 66.9 lb/ft^3 (State of Mississippi, 1990).

- Using methods described by Prats (1986), the formation fluid thermal expansion factor, the formation heat capacity, and the injection zone material heat capacity are estimated as 0.00047/°F, 1 BTU/lb-°F, and 39 BTU/ft^3-°F, respectively.

- Hydraulic conductivity is computed from an equation relating hydraulic conductivity to permeability, density, and viscosity (Freeze and Cherry, 1979). Using values for permeability, density, and viscosity presented in table 2 (363 md, 66.9 lb/ft^3, and 0.41 cP, respectively), the hydraulic conductivity is computed to be 2.6 ft/d.

Jackson County Injection Sites

This section includes the results of reviews of available literature and data conducted to quantify physical properties for the upper Wilcox and Miocene injection zones, located approximately 3,950 and 2,500 ft, respectively, below land surface in Jackson County. Physical properties for these injection zones were quantified with respect to the combined physical property requirement list previously presented. Permit applications of industries petitioning to operate Class I injection wells and standard-reference chemistry and physics texts were the primary sources of information for the reviews. With the exception of a few reports and supplementary data for the Miocene injection zone, very little additional information pertaining to the physical properties for these two injection zones was available in sources other than permit applications and standard-reference texts. The physical properties quantified for the upper Wilcox and the Miocene injection zones in Jackson County are summarized in tables 3 and 4, respectively, along with their respective references.

For clarity, some additional discussion of selected physical properties for the upper Wilcox and Miocene injection zones in Jackson County is included as follows:

UPPER WILCOX INJECTION ZONE

- Density is calculated based on specific gravity, which is reported to be about 1.045 for this injection zone (State of Mississippi, 1989). Specific gravity is the ratio of the density of a substance to the density of water. Therefore, the density of the formation fluid is about 1.05 g/cm^3 or 65.2 lb/ft^3.

- Using methods described by Prats (1986), the formation fluid thermal expansion factor, the formation fluid heat capacity, and the injection zone material heat capacity are estimated to be about 0.00033/°F, 1 BTU/lb-°F, and 34 BTU/ft^3-°F, respectively.

- Longitudinal and transverse dispersivities typically are estimated from tracer tests conducted before well construction, and values of longitudinal dispersivity typically are 5 to 20 times larger than values of transverse dispersivity (Freeze

Table 3. -- *Physical properties of the upper Wilcox injection zone in Jackson County*

[md, millidarcy; lb/in^2, pound per square inch; ft, foot; °F, degree Fahrenheit; cP, centipoise; lb/ft^3, pound per cubic foot; BTU/lb-°F, British thermal unit per pound per degree Fahrenheit; BTU/ft^3-°F, British thermal unit per cubic foot per degree Fahrenheit; BTU/ft-day-°F, British thermal unit per foot per day per degree Fahrenheit; ft/day, foot per day]

Physical property	Representative value or range of values	Reference
Physical property requirements similar to both models		
Hydrogeologic properties -		
Permeability		
Injection zone	344 md *	State of Mississippi, 1989
Confining unit	2.6x10^{-3} md *	State of Mississippi, 1989
Porosity		
Injection zone	33 percent *	State of Mississippi, 1989
Confining unit	12 percent *	State of Mississippi, 1989
Compressibility		
Injection zone	5.2x10^{-6} / (lb/in^2) *	Amyx and others, 1960
	3x10^{-6} (lb/in^2) *	Prats, 1986
Confining unit	4.0x10^{-5} / (lb/in^2)	Amyx and others, 1960
Injection zone pressure	1,870 lb/in^2 at 3,950 ft	State of Mississippi, 1989
Injection zone temperature	120 °F at 3,950 ft	State of Mississippi, 1989
Formation fluid properties -		
Formation fluid viscosity	0.65 cP	State of Mississippi, 1989
Formation fluid density	65.2 lb/ft^3 *	State of Mississippi, 1989
Formation fluid compressibility	3x10^{-6} / (lb/in^2) *	Freeze and Cherry, 1979 Prats, 1986
Physical property requirements unique to Intercomp model		
Reference temperature (top of injection zone)	120 °F at 3,900 ft *	State of Mississippi, 1989
Reference pressure (top of injection zone)	1,870 lb/in^2 at 3,900 ft *	State of Mississippi, 1989
Thermal expansion factor	0.0002/°F *	Intercomp, 1976
	0.00033/°F *	Prats, 1986
Heat capacity		
Formation fluid	1 BTU/lb-°F *	Intercomp, 1976 Prats, 1986
Injection zone material	30 BTU/ft^3-°F *	Intercomp, 1976
	34 BTU/ft^3-°F *	Prats, 1986
Longitudinal dispersivity	50 ft *	Freeze and Cherry, 1979
Transverse dispersivity	5 ft *	Freeze and Cherry, 1979
Thermal conductivity	30 BTU/ft-day-°F *	Intercomp, 1976
	16 BTU/ft-day-°F *	Prats, 1986
Hydraulic conductivity	1.5 ft/day *	Freeze and Cherry, 1979

* estimated or computed

Table 4. -- *Physical properties of the Miocene injection zone in Jackson County*

[>, greater than; md, millidarcy; lb/in², pound per square inch; ft, foot; °F, degree Fahrenheit; cP, centipoise; lb/ft³, pound per cubic foot; BTU/lb-°F, British thermal unit per pound per degree Fahrenheit; BTU/ft³-°F, British thermal unit per cubic foot per degree Fahrenheit; BTU/ft-day-°F, British thermal unit per foot per day per degree Fahrenheit; ft/day, foot per day]

Physical property	Representative value or range of values	Reference
	Physical property requirements similar to both models	
Hydrogeologic properties -		
Permeability		
Injection zone	2.0 darcies *	State of Mississippi, 1989
	330 - >2000 md	Bolin and others, 1989
Confining unit	6.5×10^{-6} md *	State of Mississippi, 1989
Porosity		
Injection zone	32 percent *	State of Mississippi, 1989
	11 - 35 percent	Bolin and others, 1989
Confining unit	13 percent *	State of Mississippi, 1989
Compressibility		
Injection zone	5.2×10^{-6} / (lb/in²) *	State of Mississippi, 1989
	3×10^{-6} / (lb/in²) *	Prats, 1986
Confining unit	5.0×10^{-5} / (lb/in²) *	State of Mississippi, 1989
Injection zone pressure	1,170 lb/in² at 2,620 ft	State of Mississippi, 1989
	550 - >1,000 lb/in² **	Bolin and others, 1989
Injection zone temperature	105 °F at 2,620 ft	State of Mississippi, 1989
Formation fluid properties -		
Formation fluid viscosity	0.71 cP	State of Mississippi, 1989
Formation fluid density	63.8 lb/ft³ *	State of Mississippi, 1989
Formation fluid compressibility	3×10^{-6} / (lb/in²) *	Freeze and Cherry, 1979; Prats, 1986
	Physical property requirements unique to Intercomp model	
Reference temperature (top of injection zone)	105 °F at 2,620 ft *	State of Mississippi, 1989
Reference pressure (top of injection zone)	1,170 lb/in² at 2,620 ft *	State of Mississippi, 1989
Thermal expansion factor	0.0002/°F *	Intercomp, 1976
	0.00025/°F *	Prats, 1986
Heat capacity		
Formation fluid	1 BTU/lb-°F *	Intercomp, 1976; Prats, 1986
Injection zone material	30 BTU/ft³-°F *	Intercomp, 1976
	33 BTU/ft³-°F *	Prats, 1986
Longitudinal dispersivity	50 ft *	Freeze and Cherry, 1979
Transverse dispersivity	5 ft	Freeze and Cherry, 1979
Thermal conductivity	30 BTU/ft-day-°F *	Intercomp, 1976
	16 BTU/ft-day-°F *	Prats, 1986
Hydraulic conductivity	7.9 ft/day *	Freeze and Cherry, 1979; Slack and Darden, 1991

* estimated or computed ** bottom-hole pressures

and Cherry, 1979). However, no tracer test results are currently available for this particular injection zone; therefore, longitudinal and transverse dispersivity are assumed as 50 ft and 5 ft, respectively (Freeze and Cherry, 1979).

- Hydraulic conductivity is computed (based on a permeability of 344 md, a density of 65.2 lb/ft^3, and a viscosity of 0.65 cP) to be 1.5 ft/d (Freeze and Cherry, 1979).

MIOCENE INJECTION ZONE

- For production fields in southwestern Alabama, Bolin and others (1989) state that Miocene permeability ranges from 330 to greater than 2,000 md, porosity ranges from 11 to 35 percent, and bottom-hole pressures range from 550 to greater than 1,000 lb/in^2.

- Density is estimated based on specific gravity, which is reported to be about 1.022 for a dissolved-solids concentration of 30,000 mg/L estimated for the Miocene injection zone (State of Mississippi, 1989). Therefore, the density of the formation fluid is about 1.02 g/cm^3 or 63.8 lb/ft^3.

- The formation fluid thermal expansion factor, the formation fluid heat capacity, and the injection zone material heat capacity are estimated using methods described by Prats (1986) to be about 0.00025/°F, 1 BTU/lb-°F, and 30 BTU/ft^3-°F, respectively.

- Longitudinal and transverse dispersivities typically are estimated from tracer tests conducted before well construction, and values of longitudinal dispersivity typically are 5 to 20 times larger than values of transverse dispersivity (Freeze and Cherry, 1979). However, no tracer test results are currently available for this particular injection zone; therefore, longitudinal and transverse dispersivity are assumed as 50 ft and 5 ft, respectively (Freeze and Cherry, 1979).

- Hydraulic conductivity is estimated (based on a permeability of 2 darcies, a density of 63.8 lb/ft^3, and a viscosity of 0.71 cP) to be 7.9 ft/d (Freeze and Cherry, 1979). This value of hydraulic conductivity is within the range of measured hydraulic conductivities for the Miocene aquifer system (Slack and Darden, 1991).

SUMMARY

Underground injection of industrial waste is a disposal process in which liquid waste is stored beneath the surface of the earth. Class I injection wells are used to inject hazardous or non-hazardous liquid waste below a formation containing the lowermost underground source of drinking water located within one-quarter of a mile of the well bore. Computer models can be used to simulate the effects of injection and to evaluate potential hydrogeological problems over time. For this report, available literature and data were reviewed to quantify data requirements for computer simulation of hydrogeologic effects of liquid waste injection in southeastern Mississippi. Emphasis of each review was placed on quantifying physical properties of current Class I injection zones in Harrison and Jackson Counties.

Mississippi currently (1994) has three Class I injection sites containing a total of six wells. Hazardous waste is injected into three wells completed in the Washita-Fredricksburg injection zone located approximately 9,800 to 10,000 ft below land surface in Harrison County. Hazardous waste is also injected into one well completed in the upper Wilcox injection zone located approximately 3,950 ft below land surface and into one well completed in the Miocene injection zone located approximately 2,500 ft below land surface in Jackson County. Non-hazardous waste is injected into one well in Hinds County.

Several computer models are available to simulate Class I injection effects. The two models selected for analysis in this report are the Basic Plume Method and the Intercomp model. The Basic Plume Method commonly is used in permit applications, and the Intercomp model generally is accepted and used in injection-related research. This report includes a brief description and listing of the general input data requirements for the two selected models. The input data requirements are then compared and combined into a single data requirement list. The combined list is inclusive for physical properties of injection zones only; injected waste and well properties are not included because such information is site-specific by industry, which is beyond the scope of this report.

Results of the reviews of literature and available data indicated that permit applications of industries petitioning to operate Class I injection wells and standard-reference chemistry and physics texts were the primary sources of information used to quantify physical properties of injection zones in Harrison and Jackson Counties. With the exception of a few reports and supplementary data for the Miocene injection zone in Jackson County, very little additional information pertaining to physical properties of the injection zones was available in sources other than the permit applications and standard-reference texts.

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