ASSOCIATED WASTE REPORTS

EXECUTIVE SUMMARY

January 2000

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In Section 3001(b)(2)(A) of the 1980 Amendments to the Resource Conservation and Recovery Act (RCRA), Congress conditionally exempted several types of solid wastes from regulation as hazardous wastes. Among the categories of wastes exempted were "drilling fluids, produced waters, and other wastes associated with the exploration, development, and production of crude oil or natural gas...."

RCRA Section 8002(m) required the U.S. Environmental Protection Agency (EPA) to study these wastes and submit a report to Congress evaluating the status of their management. Section 3001(b)(2) also required EPA either to promulgate regulations under RCRA Subtitle C for these wastes or to determine that such regulations were unwarranted. In December of 1987, EPA completed the *Report to Congress on the Management of Wastes from the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy* (EPA/530-SW-88-003). This was a comprehensive three-volume report that documented, as of 1985, the quantities and characteristics of oil and gas wastes, the means by which the wastes were and could feasibly be managed, the damages caused and potential risks posed by mismanagement of the wastes, the adequacy of existing government and private measures to prevent or mitigate adverse effects, and the potential cost and economic impacts of alternative waste management practices.

On July 6, 1988, the Agency made a regulatory determination that oil and gas exploration and production (E&P) wastes did not warrant regulation as hazardous wastes under Subtitle C of RCRA (*Federal Register*, volume 53, number 129, pages 25446-25459). The Agency concluded that the wastes could be better controlled through improvements to existing State and Federal regulatory programs. The wastes exempted from regulation as hazardous wastes include produced water and drilling muds, which are generated in extremely large volumes, and other wastes uniquely associated with oil and gas exploration and production, which are generated in much smaller volumes. Table ES-1 below identifies the associated wastes that EPA has identified as being exempt from regulation as hazardous wastes.

On March 22, 1993, EPA provided clarification on the scope of the E&P exemption with respect to wastes generated by crude oil reclamation operations, service companies, crude oil pipelines, gas plants and feeder pipelines, and natural gas storage fields (*Federal Register*, volume 58, number 53, pages 15284-15287). The FR notice did not change the scope of the E&P exemption, instead it clarified the existing regulatory status of wastes generated by these segments of the industry. Similarly, in May 1995, EPA published a booklet titled "Crude Oil and Natural Gas Exploration and Production Wastes: Exemption from RCRA Subtitle C Regulations" (EPA530-K-95003). This booklet explains, in lay terms, the scope of the E&P exemption, how to determine the regulatory status of E&P wastes, and provides examples of exempt and non-exempt E&P wastes.

TABLE ES-1. Associated Wastes

Dehydration/Sweetening Wastes

- Glycol-based compounds
- Amines
- Sulfinol
- Caustic solutions
- Water
- Backwash
- Hydrogen sulfide scrubber liquid
- Spent catalyst
- Filter media (cloth, paper, charcoal)
- Glycol or amine filters
- Precipitated amine sludge
- Spent iron sponge (water slurries/sludge, wood chips)
- Spent molecular sieve
- Slurries of sulfur and sodium salts
- Contaminated soil
- Naturally Occurring Radioactive Materials

Workover and Completion Wastes

- Well completion, treatment and stimulation fluids
- Surfactants
- Weighting agents/viscosifiers
- Thinners
- Muds (water- or oil-based associated with workovers)
- Produced water (associated with workovers)
- Crude oil
- Acidizing agents
- Corrosion inhibitors
- Gels
- Solvents
- Paraffin solvents and dispersants
- Fracturing media
- Used filters
- Biocides
- Packing fluids
- Detergents
- Defoamers
- Paraffin
- Sludges
- Pieces of downhole equipment
- Inert materials from downhole mechanical repair (produced sand, formation or pipe scale, cement cutting and slurries)
- Naturally Occurring Radioactive Materials

Spent Filter Media

- Water with surfactant (backwash)
- Drainage fluids
- Oil
- Coal
- Gravel
- Sand
- Diatomaceous earth
- Particulates
- Naturally Occurring Radioactive Materials

Tank Bottoms

- Solids
- Sands
- Emulsions
- Accumulated heavy hydrocarbons (asphaltic or paraffinic)

Oily Debris[1]

- Rags
- Sorbent materials

Crude Oil

- Waste crude from primary field operations and production
- Liquid hydrocarbons removed from production stream but not from oil refining (drip gas)

(continued)

TABLE ES-1. Associated Wastes (continued)
Spent Filters Socks Cartridges Canisters Naturally Occurring Radioactive Materials
Cooling Water Cooling tower blowdown Boiler water Scrubber liquids Steam generator waste from steamflood operations
Produced Sand Sand Wet sludge containing oil and water
Contaminated Soil Hydrocarbon-bearing soil Produced water-contaminated soil Sulfur-contaminated soil from sulfur recovery units NORM-contaminated soil
Untreatable (Tight) Emulsions Caustic solutions Emulsion breakers (surfactants) Dehydration chemicals Brine Hydrocarbons Silt Scale
Pigging Wastes (from gathering lines and producer-operated gathering lines) Hydrocarbon solids Wax formed and deposited in pipelines and process equipment Paraffins[2] Rust Scale Debris Naturally Occurring Radioactive Materials
Used Solvents and Degreasers Spent acids Caustic solutions

(continued)

TABLE ES-1. Associated Wastes (continued)
Miscellaneous Wastes
Pipe scale, hydrocarbon solids, hydrates, and other deposits removed from piping and equipment prior to transportation
Waste from subsurface gas storage and retrieval
Constituents removed from produced water before injection or other disposal
Gases from the production stream (e.g., H_2S, CO_2, volatilized hydrocarbons)
Light organics volatilized from exempt wastes in reserve pits or impoundments or production equipment
Production line hydrotest/pressure fluids utilizing produced water
Material ejected from a producing well during blowdown
SOURCE: "List of Associated Wastes Generated by the Exploration, Development, and Production of Crude Oil and Natural Gas." Unpublished table prepared by U.S. Environmental Protection Agency, Office of Solid Waste.
NOTES:
1 Oily debris is exempt from regulation under Subtitle C if its generation is intrinsic to exploration and/or production operations.
2 Paraffins are exempt from regulation under Subtitle C if they are from gathering/ production lines. They are not exempt if they are from transportation lines.

In the 1988 regulatory determination, EPA indicated that it would improve existing Federal regulatory programs, work with States to improve their programs, and work with Congress to develop any additional statutory authorities that might be required. Since the completion of the *Report to Congress* and the regulatory determination, EPA has taken a number of steps to improve existing regulatory programs and to enhance its understanding of the industry and the wastes generated. For example, under the Clean Water Act, EPA has promulgated effluent limitations guidelines for offshore oil and gas operations and effluent limitations guidelines for coastal operations (*Federal Register*, volume 61, number 242; pages 66085-66130). Under the Safe Drinking Water Act, EPA has refined the regulatory program for underground injection control. EPA's Office of Solid Waste also provided funding to the Interstate Oil and Gas Compact Commission (IOGCC) to develop guidelines for an effective State regulatory program for exploration and production wastes. The guidelines, "EPA/IOCC[1] Study of State Regulation of Oil and Gas Exploration and Production Wastes," were published in December 1990 and provide administrative and technical criteria for State regulatory programs. In May 1994, IOGCC published revised and updated guidelines titled "IOGCC Environmental Guidelines for State Oil and Gas Regulatory Programs." IOGCC encourages States to incorporate EPA's waste management hierarchy (i.e., source reduction, recycling, treatment, and disposal) into their regulatory programs. The guidelines provide specific examples of source reduction and waste minimization opportunities. IOGCC has reviewed a number of major State regulatory programs for consistency with these guidelines. The IOGCC reviews highlight the strengths of a State's regulatory program as well as its

[1] Prior to July 1, 1991 the Interstate Oil and Gas Compact Commission (IOGCC) was known as the Interstate Oil Compact Commission (IOCC).

weaknesses relative to the guidelines. When deficiencies are identified, the IOGCC review team provides recommendations to the State for effecting improvements. This approach provides a constructive appraisal of a reviewed State's program and facilitates the exchange of useful information and ideas among the States. To date, IOGCC has completed reviews of 17 States representing approximately 95 percent of U.S. production. In addition, IOGCC has conducted "follow-up" reviews of three States to determine how these States have responded to the IOGCC review team's recommendations. EPA also has funded a number of other State initiatives, including a grant to the Railroad Commission of Texas to develop an oil and gas exploration and production (E&P) waste minimization and outreach program for operators in Texas and a grant to the Alaska Department of Environmental Conservation to identify and promote pollution prevention opportunities for the oilfield service industry. Although discussions of typical waste management and disposal practices are included in this report, States' E&P waste management regulatory programs are not addressed. An overview of States' E&P waste management regulatory programs and program improvements can be found in the U.S. Department of Energy/IOGCC report titled "Oil and Gas Exploration and Production Waste Management: A 17-State Study" published in June 1993. Additional sources of information on State regulatory programs include the individual reports of IOGCC regulatory program reviews and follow-up reviews.

Besides these initiatives, EPA has continued to compile and analyze information on the wastes generated by the oil and gas exploration and production industry, as well as waste minimization and pollution prevention practices. The 1987 *Report to Congress* necessarily focussed primarily on produced water and drilling muds, since these were estimated to constitute over 98 percent of the total industry wastestream. Consequently, studies and data on associated wastes have been limited.

EPA has examined readily available information to enhance its understanding of these wastes, including the means by which they are generated and the methods used for their management and disposal. The results of its preliminary investigations are presented in the three sections of this report. The sections respectively describe:

- Tank bottoms and oily debris
- Dehydration and sweetening wastes, including iron sponge
- Completion and workover fluids.

Each of these associated waste categories is discussed in a separate, stand-alone section that covers the activities which give rise to the wastes, the nature and characteristics of the wastes, typical waste management practices, potential environmental effects from mismanagement of the wastes, and waste minimization and pollution prevention opportunities. The report is based on current publicly available information that was identified by EPA through industry contacts, literature reviews, American Petroleum Institute (API) database searches, library searches, and contacts with other Federal agencies and State agencies. In addition, EPA conducted waste water and solid waste sampling and analysis programs in 1992 to supplement available waste characterization data. A discussion of the solid waste project objectives, sampling procedures, analytical methods, data precision and data accuracy are presented in a separate report titled "Associated Waste Report: 1992 Sampling and Analysis."

EPA's associated waste investigations revealed that there is a wide variety of information available on the wastes, although with few known exceptions there has been no systematic examination of these wastes since the 1987 Report to Congress. Two notable exceptions are a study sponsored by the Western States Petroleum Association detailed in a March 1993 report titled "Evaluation and Review of the Petroleum Industry's Road Mix Process (Volume I)" and a study by the Gas Research Institute (GRI) of gas industry wastes detailed in a May 1993 topical report titled "Sampling and Analysis of Wastes from Gas Industry Operations." A number of other studies have been conducted and reported recently on the effectiveness of E&P waste management methods and are referenced throughout this report as appropriate. Notwithstanding these studies, a 1985 associated waste survey by the American Petroleum Institute remains the only comprehensive estimate of the volumes of associated wastes that are generated and the methods that are used to manage these wastes. Availability of waste characterization data has improved somewhat, although there are still relatively few samples overall. Available sampling data indicate that the waste categories studied here generally contain few constituents at levels exceeding hazardous criteria. However, several of the wastes frequently exhibit the RCRA toxicity characteristic for benzene and, infrequently, for lead. It should be noted that the toxicity characteristic list of contaminants does not include all the possible toxic constituents that may be found in oil and gas wastes. For example, an oil and gas waste might contain benzo(a)pyrene, but benzo(a)pyrene is not a constituent regulated by the toxicity characteristic.

EPA used the Toxicity Characteristic Leaching Procedure (TCLP) to evaluate the toxicity of samples. However, oil and gas exploration and production (E&P) wastes are generally not disposed in municipal landfills. Additionally, sludge and oily samples can create operational and equipment difficulties leading to unreliable analytical results. This was a problem with a number of EPA's 1992 tank bottom TCLP samples. Therefore, as stated in the 1987 Report to Congress,"[t]his test may not reflect the true hazard of the waste when it is managed by other methods." It is also emphasized that the limited waste characteristics data are highly variable, which indicates that sampling data cannot be considered statistically representative of all associated wastes of these categories. Also, as in the 1987 *Report to Congress*, there are very few instances of documented damages involving tank bottoms, workover and completion wastes, or gas conditioning wastes.

Recent nationwide interest in pollution prevention has not overlooked the oil and gas industry, and available information includes a number of opportunities which may be appropriate in each of these three associated waste areas. Generally, toxicity reduction and reclamation options appear the most readily applicable, although process modifications resulting in significant source reductions may prove attractive in a number of cases. EPA, as well as API and GRI, is continuing to investigate opportunities for pollution prevention and waste minimization.

Finally, IOGCC's review of State regulation of oil and gas wastes indicates that most States have adopted the Federal exemption from hazardous waste regulation for exploration and production wastes. Some states, notably California, have retained the authority to regulate selected wastes as hazardous, however. Where wastes are not regulated as hazardous wastes, they may be addressed under States' broad solid waste management programs or under more specialized programs specific to this industry. It should be noted that exploration and production wastes, like most industrial wastes, are generally not regulated by waste type, but rather are regulated in the context of the units in which they are managed. No attempt was made in these reports to describe or assess States' E&P waste regulatory programs. Similarly, industry waste management practices are not assessed in these reports.

The sections below very briefly summarize the three groups of associated wastes discussed in this report. It should be noted that EPA is aware that the literature on oil and gas exploration and production is voluminous and growing rapidly. In particular, the literature on the environmental performance of industry operations is growing at an unprecedented rate. As a result, there may be important references that the Agency overlooked in its search for relevant information. Also, the descriptions of industry operations do not encompass all possible variations of operating practices that exist across the industry. Accordingly, this report should not be viewed as a comprehensive analysis. Instead, it should be used as a reference document on the generation, management, and characteristics of these wastes. EPA would welcome any supplementary information on these and other wastes generated by the oil and gas exploration and production industry.

Tank Bottoms

Among the oil and gas exploration and production (E&P) wastes exempted from Subtitle C of RCRA are "basic sediment and water (BS&W) and other tank bottoms from production storage facilities that hold product and exempt waste." Tank bottoms are generally defined as the liquids and residue that collect in the bottom of product or water storage tanks, or that collect in the bottom of vessels used to separate impurities from the production stream (separators, free water knockouts, heater treaters). Accordingly, tank bottoms may be associated with crude or partially treated oil, produced water, separator wastes, pigging wastes, emulsion crackers, or any of a number of liquid or semi-solid wastes.

Throughout the oil or gas production processes, oily debris, such as soil, rags, and absorbent materials, may be generated due to minor leaks and spills. Additional oily debris may be generated during well completions and workovers, gas conditioning, and water treatment.

The only systematic study of the quantities of crude oil tank bottoms and oily debris generated in the U.S. is a survey conducted in 1985 by the American Petroleum Institute. The API study extrapolated State and National estimates of associated waste volumes from member company survey responses and the percentage of State and National crude oil production represented by those respondents. According to the survey, U.S. operators generated 1,232,000 barrels (42 U.S. gallons per barrel) of tank bottoms and 1,261,000 barrels of oily debris in 1985. Tank bottoms are generated continuously at nearly all oil and gas production operations. The universe of generators of crude oil tank bottoms is estimated to be in the hundreds of thousands, generally including all sites where product is stored or treated. The volumes generated at individual sites could be expected to be relatively low, although National totals are significant. Although estimates for the number of generators of oily debris are not available, this number could be expected to be at least as large as for tank bottoms.

API's results indicate that the quantity of tank bottoms and oily debris reported by respondents was highly variable on per-well and per-unit-production bases. For instance, results indicate that for the year surveyed, roughly 1.9 barrels of tank bottoms wastes were generated per producing oil well, nationwide, with State estimates ranging from less than 0.1 to 11.9 barrels per well. Similarly, survey results indicate that roughly two barrels of oily debris were generated per producing oil well, nationwide, with State estimates ranging from less than 0.1 to 1,036 barrels per well. Factors likely to have caused the wide variation in survey responses include the composition of production streams of the individual operators and the individual States, the nature of the production operations (e.g., steam flood v. primary production), the nature of the producing formation, State regulation, and respondent interpretation of survey definitions.

Analytical results for a total of 77 samples (excluding duplicates) of tank bottoms and oily debris were reviewed for this report, including 74 tank bottom samples and 3 oily debris samples. The sample results were compiled from a variety of publicly available sources, as well as from EPA's own sampling efforts in 1992. EPA offered sample splits to operators at each facility. Five facilities accepted sample splits; however, analytical data were available for only one facility. There is considerable disagreement between EPA's results and the facility's results. Split sample data are included in the Appendix D for comparison with EPA's data.

Ideally, crude oil tank bottoms and produced water storage tank bottoms samples should be collected after the oil or produced water have been removed from the tank. However, since fluids are not routinely removed from crude oil and produced water storage tanks on a predictable basis, it is rarely possible to schedule sampling episodes to coincide with the removal of fluids. Therefore, most crude oil and produced water tank bottom samples must be collected with oil or produced water in the tank by lowering a dredge through a hatch in the top of the tank and pulling the sample up through the fluid column. Consequently, the oil or water content of the tank bottom sample may be higher than would be the case if the sample was collected under ideal conditions and not pulled through the fluid. As a result, the sample may exhibit some characteristics (e.g., ignitability) or higher concentrations of certain constituents (e.g., benzene or chlorides) typically associated with the crude oil or produced water. During EPA's 1992 solid waste sampling effort, samples were collected using a dredge for four of 10 tank bottom samples, one of two duplicates, and two of three TCLP samples. A dredge was also used to collect two of three produced water tank samples and the sole duplicate. These are identified in Table D-1 of Appendix D.

In general, TCLP analyses of tank bottom samples resulted in frequent exceedences of the RCRA Toxicity Characteristic (TC) level for benzene (500 μg/L), and infrequent exceedences of the TC level for lead (5 mg/L). No other constituents were observed in any sample above TC levels. Seventeen of 32 samples analyzed exhibited RCRA ignitability (flash point below 140 degrees F). One of two samples analyzed displayed RCRA reactivity for reactive sulfide. It should be noted that there are no appreciable or consistent differences in the data for tank bottoms from production operations and data for tank bottoms from crude oil reclaimers.

Overall, results of TCLP and total constituent analyses were highly variable across samples, with constituent concentrations often varying between samples and facilities by several orders of magnitude. Available information is insufficient to confirm which factors most influence the characteristics of tank bottom wastes. However, a number of factors may be considered important such as the nature of the treatment vessel or storage tank, the nature of the production stream, the nature of the formation, the treatment process, the composition of down-hole treatment additives, the frequency of vessel cleaning, and sampling methodology.

The API survey also provides the only systematic review of the methods used for waste management of tank bottoms and oily debris. The survey identified eight categories of management and disposal: recycling/reuse (recycled by sending to crude oil reclaimers), roadspreading, landspreading, on-site pits, on-site burial, off-site commercial facilities, incineration (tank bottoms only), and other methods. Results of the survey indicate that more than 50 percent of tank bottoms generated nationwide in 1985 were managed in off-site commercial facilities. Much of the remainder was roadspread (21 percent), reclaimed (14 percent), or landspread (7 percent). Respondents indicated that two-thirds of all oily debris was spread on roads, with nearly all the remainder sent to off-site commercial facilities.

Potential environmental effects associated with the management of tank bottoms and oily debris vary with the management method and site-specific factors such as geology and hydrogeology. For instance, landspreading and roadspreading could present a risk of off-site migration of constituents of concern due to surface water run on and runoff. In cases of high salinity and/or high oil and grease concentrations, impacts to soils and/or vegetation could result from off-site transport. In the case of landspreading, the potential impacts would depend largely on the rates of application and the total volumes. On-site pits and on-site burial could each present potential impacts to ground water from downward migration of constituents of concern, and to surface water and soils if the integrity of the structure is compromised. The potential for any such impacts is highly site-specific. It should be noted that EPA has not identified any damage cases directly attributable to management of tank bottoms or oily debris.

Crude oil reclamation presents a viable pollution prevention opportunity for generators of tank bottoms. Crude oil reclamation facilities currently operating in the U.S. accept off-specification crude oil as well as tank bottoms for recycling/reclamation. There are roughly 320 reclaimers in operation in the 20 largest oil producing States, and these operators generate more than 2.4 million barrels of saleable crude oil per year. Crude oil reclamation can potentially reduce the volume of crude oil tank bottoms by 70 percent, thereby reducing wasted product as well as disposal costs.

Completion and Workover Fluids

Among the oil and gas exploration and production (E&P) wastes exempted from Subtitle C of RCRA are "well completion, treatment, and stimulation fluids" and "workover wastes." Well "completions" include those activities that may be necessary to allow a well, once drilled, to produce oil or gas. These activities include installing and cementing casing, installing the production tubing and downhole equipment, repairing damage that drilling may have caused to the formation, and possibly stimulating the well. During a well's active life, periodic "workovers" are necessary. Workovers can include a number of procedures intended to maintain or enhance production. These can include repairing or replacing downhole equipment, removing accumulated scale or paraffin from tubing or casing, and stimulating the formation to restore or enhance production. Wells are treated/stimulated, by treating with acid or other chemicals and/or by fracturing, during completion or workover or both: it is common for wells to be treated at completion and then periodically throughout their lives.

The wide range of tasks that may be accomplished by workovers and completions results in a variety of wastes which may be generated by these activities. Completion and workover wastes range from the base fluids (together with additives) and formation fluids to cement that circulates out of the well or that is brought back to the surface in produced fluids. Also included are damaged tubing and pumps and other equipment retrieved from downhole. The wastes may also include drilling muds (from return flows), produced water, crude oil, and a wide range of other wastes such as used filters, paraffin, sludges, pieces of downhole equipment, produced sand, drill and cement cuttings, pipe scale, etc.

The only systematic study of the quantities of completion and workover fluids that are generated in the U.S. remains the API associated wastes survey referred to above. That survey provided results for a subset of all completion and workover wastes; most importantly, it excluded non-fluid wastes, and fluids disposed via on-site underground injection. The API study extrapolated State and National estimates of completion and workover waste volumes from member company survey responses and the percentage of State and National crude oil production represented by those respondents.

API calculated that U.S. operators generated approximately 5.6 million barrels of completion and workover fluids in 1985, excluding the fluids which were disposed via on-site underground injection. No estimates of the volume of non-fluid wastes generated by completion and workover operations are currently available.

Completion and workover fluid compositions could be expected to vary widely depending on the nature of the formation and the tasks to be accomplished by the operation. Fluids are selected for their ability to control subsurface pressures, maintain the stability of the well, keep solids in suspension, and perform specialty functions. They must also be compatible with the formation and minimize corrosion to tubing, casing, and downhole equipment. A wide variety of treatment chemicals are added to completion and workover fluids to enhance the fluid's ability to accomplish its function and to reduce or mitigate operating problems. Additives include surfactants, corrosion inhibitors, paraffin solvents/dispersants/inhibitors, biocides, defoamers, viscosifiers, lost circulation materials, dispersants and thinners, scale inhibitors, buffers, flocculants, and friction reducers.

Very little information on the characteristics of completion and workover fluids was found to be available. Of more than 108,000 acidizing and hydraulic fracturing jobs performed annually from 1982 through 1987, and nearly 143,000 performed annually between 1987 and 1992, analytical data were collected on a total of 21 completion and workover fluids. Seven of these samples were collected by EPA in 1992. Accordingly, one cannot be assured that the analytical results are representative of all completion and workover wastes.

In general, analytical results were highly variable with respect to constituent concentrations. Few of the non-EPA samples were analyzed for organics. Of the seven samples which were analyzed for benzene, six exceeded the TC level of 500 μg/L for this constituent. One sample exceeded the TC level for lead. No other constituent was detected in any sample at concentrations that exceeded the toxicity characteristic threshold level.

The API associated waste survey also remains the only comprehensive examination of the means by which completion and workover fluids are managed in the United States. The survey reported the volumes of fluids managed by the following methods: recycling/reuse (recycled by sending to crude oil reclaimers), roadspreading, landspreading, on-site pits, on-site burial, surface discharge, off-site commercial facilities, and other methods.

The API study indicated that most completion and workover fluids in the survey were sent to off-site commercial facilities. It is likely that the largest part of this volume is sent to off-site Class II underground injection control (UIC) wells. As noted above, the API survey did not report volumes of fluids injected in on-site wells, although API independently estimated the volume injected in on-site wells to be more than 12,000,000 barrels, over twice the volume of fluids managed in all other ways combined.

For the 1987 Report to Congress, EPA documented 61 damage cases that met the documentation standards of RCRA Section 8002(m)(c). Generally, these cases were the result of practices that were in violation of State regulations at the time of occurrence or that would be in violation of current State regulations. Of the 61 damage cases, only two were reported to involve completion and workover fluids - specifically, fracturing fluids. In one case, damages to livestock, soil, and a domestic water supply were found to have occurred after produced water, oil, drip gas, detergents, fracturing fluids, and waste production chemicals were disposed in a ditch. In the other case, a domestic water supply was found to be contaminated with natural gas and fracturing fluid that resulted from a malfunction of the fracturing process used on an adjacent gas well. The malfunction allowed natural gas and fracturing fluid to migrate into and contaminate the domestic water source.

Potential migration of wastes to underground drinking water sources would be the primary concern associated with underground injection of workover and completion fluids. The Report to Congress cited many instances where underground injection has resulted in such impacts. However, none of the cases involved completion and workover fluids. Since releases from underground injection activities are typically the result of improper operation and maintenance of the injection well (e.g., casing leaks) rather than a function of the injected fluid, injecting completion and workover fluids for disposal would not pose any greater or less risk than injecting produced water.

Specialty fluids such as completion and workover fluids provide many opportunities for waste minimization and pollution prevention. For instance, closed loop fluid circulation systems equipped with fluid filters can extend the life of specialty fluids while reducing the quantity of waste disposed in pits and tanks or injected. A number of substitute chemicals for use as thinners, corrosion control additives, and biocides, each of which demonstrates lower toxicity, are currently available for use in drilling muds and may be equally suitable for completion and workover fluids. Generally, the attention currently being paid to reducing the volume and toxicity of drilling muds should result in readily applicable modifications to completion and workover fluid designs.

Dehydration and Sweetening Wastes

Among those exploration and production (E&P) wastes exempted from regulation as hazardous wastes are "gas plant dehydration wastes..." and "gas plant sweetening wastes...." Dehydration and sweetening wastes result from conditioning activities required to remove undesirable impurities in natural gas production streams. Dehydration is the removal of water vapor from production streams. Conditioning for the removal of acid gases, including hydrogen sulfide (H_2S) and carbon dioxide (CO_2), is called sweetening.

Dehydration and sweetening may each be accomplished through a number of distinct methods. Dehydration methods may include liquid and solid desiccant dehydration, and refrigeration dehydration, with glycol dehydration dominating the industry. Amine sweetening, iron sponge sweetening, potassium carbonate sweetening, and physical solvent sweetening are among the more than 30 distinct methods of sweetening.

Both sweetening and dehydration may be performed in small field facilities or at large central plants receiving product from multiple well fields. Recent data indicate that there are 731 centralized gas plants in operation in the U.S., of which all perform some level of gas dehydration and 278 perform some level of gas sweetening. No information regarding the total number of field sweetening and dehydration units is currently available, however, so it is not possible to accurately estimate the total number of sites generating dehydration and sweetening wastes.

Dehydration wastes include desiccant reboiler sludge, filter sludge and spent filter media, spent desiccant, regeneration condensate (i.e., the water removed from the gas stream), and miscellaneous desiccant spills. A recent study by GRI provides national estimates (in the 1988 to 1990 time frame) of some sweetening and dehydration wastes. The nationwide generation rate of dehydration water, including regeneration condensate, was reported to be roughly 1.3 million pounds per day (lbs/d). Glycol and gas filters account for roughly 20,000 lbs/d. Roughly 13,000 lbs/d of spent solid desiccant is generated, while spent glycol accounts for an additional 2,100 lbs/d. GRI estimated that glycol reclaimer sludges account for only 71 lbs/d nationally. It should be noted that GRI estimated contributions from gas plants and from underground storage operations and pipeline compressor stations. Wastes from pipelines and compressor stations may not be exempt from RCRA Subtitle C, since they may not be associated with field production activities. Additionally, GRI's estimates exclude field dehydration operations.

Like dehydration facilities, sweetening units may generate a wide variety of wastes. Among the wastes generated at such facilities are spent amine, amine filter media, backwash, precipitated amine sludge, iron sponge, and hydrogen sulfide scrubber liquid and sludge. Other wastes which may be generated at sweetening plants include amine reclaimer sludge, spent sweeteners other than amine and iron sponge, and regeneration condensate. Additionally, flare pit sludge and wastes from sulfur recovery may be generated at sweetening facilities. The GRI study estimates the national generation rate of several categories of sweetening wastes. For example, the study estimates that 82,000 lbs/d of filters from acid gas removal are generated. Water/wastes from acid gas removal are estimated at 37,000 lbs/d, and water/wastes from liquid gas sweetening are estimated at 2,200 lbs/d. Again, the study includes contributions from gas plants as well as from underground storage and compression operations, but excludes field units.

Various sources of qualitative and quantitative data on dehydration and sweetening waste characteristics were compiled and reviewed for this report. The GRI study presents the most comprehensive investigation of gas industry wastes performed to date, and includes analytical results for 63 dehydration and sweetening waste samples representing 20 waste categories. Additional data were obtained from Canadian gas industry studies of sweetening wastes, symposia on sulfur recovery and gas conditioning processes, various general literature sources, and EPA's 1992 sampling program.

Analytical results for dehydration waste samples indicated that some of the wastes may exhibit hazardous characteristics as defined under RCRA. For instance, spent filter samples frequently exceeded TC levels for benzene and in two cases exceeded the RCRA threshold for reactive sulfide. Spent glycol and glycol sludges frequently exceeded TC levels for benzene and two samples displayed flash points below 140 degrees F. Seven of eight reboiler condensate samples exceeded TC levels for benzene. All dehydration waste samples generally showed low metals concentrations, although several samples collected from the same region in the Middle Atlantic showed arsenic concentrations in excess of TC levels.

Fewer sample results were available for sweetening wastes. Those samples available indicated that spent amines may exceed TC levels for benzene and may be ignitable. Qualitative and total constituent data indicate that filters and filter sludges may contain high metals and organics concentrations. For many sweetening agents, no TCLP data were obtained.

Overall, characterization information for dehydration and sweetening wastes indicated that the wastes are highly variable with respect to concentrations of toxicity characteristic constituents. Concentrations are likely to vary strongly with the composition of the feed gas and the nature of the producing formation. Additionally, data suggest that the location of the conditioning unit in the overall plant process train may influence the concentration of impurities. The nature of the conditioning agent and the operating conditions of the unit are also likely to play a role in the accumulation of contaminants.

The American Petroleum Institute associated waste survey (API 1988) is the only publicly available, systematic study of the means by which dehydration and sweetening wastes are managed in the United States. The survey reported the volumes of fluids managed by the following methods: recycling/reuse, roadspreading, landspreading, injection, incineration, on-site pits, on-site burial, off-site commercial facilities, and other methods. The study, however, extrapolates State and national estimates of wastes generated and managed according to the percentage of crude oil production, not gas production, represented by survey respondents. The survey explicitly excludes gas plant wastes from consideration, and excludes all solid (i.e., non-liquid) wastes from the definitions of dehydration and sweetening wastes. Additionally, the survey excludes regeneration condensate from the dehydration and sweetening waste categories. Accordingly, the results are useful, at best, as a qualitative indication of predominant management methods employed at field units. Generally, the survey indicates that underground injection is by far the predominant method of disposal of liquid dehydration and sweetening wastes, with off-site disposal accounting for much of the remainder. Spent iron sponge is reportedly typically managed through on-site burial and on-site pits, with off-site disposal accounting for most of the remainder. Currently available information on waste management practices at gas plants is limited. However, a paper prepared by GRI and ENSR Consulting[2] provides an informative overview of waste management and waste minimization in the natural gas industry.

As with other associated wastes, the potential environmental effects associated with the management of sweetening and dehydration wastes depends largely on the management method. The 1987 *Report to Congress* cites contamination of underground sources of drinking water as a potential impact associated with underground injection. However, in preparing this report, EPA has not identified any cases of damages associated with injection of dehydration and sweetening wastes. Surface discharges of regeneration condensate have been implicated in cases of groundwater contamination, but this practice is reportedly no longer employed.

Dehydration and sweetening operations may be amenable to a number of pollution prevention and waste minimization opportunities. Sulfur recovery provides a graphic example of the benefits of source reduction. Sulfur recovery from natural gas operations resulted in the production of nearly 3 million metric tons of saleable sulfur in 1991, equal to approximately half of the total U.S. sulfur output. Co-current (versus counter current) extractors in caustic and amine NGL sweetening units can be used to reduce the total volume of sweetening solvent required in a plant by as much as 75 percent. Such process changes reduce the solvent costs of the plant while simultaneously reducing the quantity of waste amines or caustic generated. Toxicity reduction at some operations can be accomplished by substituting less toxic alternative materials in place of formaldehyde-based sweetening agents. Finally, amine or Stretford solution reclamation can prolong the useful life of the solvents and reduce the quantity of materials requiring disposal.

[2] Fillo, John F. and Evans, James M.: "Natural Gas Industry Waste Production and Management Practices," paper SPE 29716 presented at the SPE/EPA Exploration and Production Environmental Conference held in Houston, TX, March 27-29, 1995