Tank Bottom Waste Processing Using the TaBoRR^{TM} Process

**Topical Report
February 1994 - January 1995**

Robert M. Satchwell

February 1995

Work Performed Under Contract No.: DE-FC21-93MC30126

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Western Research Institute
Laramie, Wyoming

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EXECUTIVE SUMMARY

Western Research Institute (WRI) has developed a process titled TaBoRR™ (Tank Bottom Recovery and Remediation) that remediates tank bottom wastes and recovers refinery acceptable crude oil. This work provides: support for the field demonstration unit; equipment, materials, and labor for construction and operation of a laboratory unit; and numerical and economic modeling of the process.

This report includes an interim update on Task 1.4 entitled "Tank Bottom Waste Processing using the TaBoRR™ Process," which includes the results of the work to date. The objective of this work is to develop information for the successful deployment of WRI's patented TaBoRR technology. This objective is being accomplished by providing: technology support to the field demonstration unit, the design and operation of a laboratory process unit, and numerical and economic analysis. The results of the work performed under this task are reported.

Presently, the level of effort in support of the field demonstration unit has been limited to analysis of two sources of tank bottom wastes. The results of these analyses indicate that the samples contain solid concentrations from 1 to 9 wt % and water concentrations between 10 and 53 wt %. Certain analytical separation techniques should be avoided in the separation of components contained in tank bottom wastes. Also reported are the true boiling point curves for the crude oil present in the tank bottom wastes. All other support of the field demonstration unit has been suspended until warmer weather allows for the operation of the field unit.

The design of the laboratory unit is complete and is reported. Component sizes obtained during the design effort have been confirmed by a numerical simulator. Currently, the construction of the laboratory unit is approximately 95% complete. Shakedown tests and experimental procedures will be performed and developed after construction is complete. Economic and process modeling will be performed after the completion of experiments with tank bottom wastes.

INTRODUCTION

During the production life of an oil well, both basic sediments and water (BS&W) are produced. Since refineries set strict limits on BS&W, the maximum BS&W that will be removed from the field production stream is limited by separation economics. The unacceptable stream is discarded as tank bottom waste. Commonly, the waste exists as a very stable emulsion containing substantial amounts of oil. Routinely, these tank bottom wastes are handled by oil salvage companies who haul them to storage facilities, such as permitted surface pits or storage tanks.

These storage facilities are generally permitted and/or licensed by local governmental agencies. Currently, new permits are not being granted because either the environmental regulations are too stringent, or new storage facilities are too expensive to construct and bond. In the past, these permitted pits were often ignited to provide additional space for tank bottom wastes. However, this is no longer a viable solution. Thus, new technologies are needed to reduce the volumes of these wastes and ultimately remediate such sites.

A typical tank bottom waste is composed of 1 to 30 wt % water and 1 to 40 wt % solids, with the balance being crude oil. Based on the significant amount of oil present, these wastes can be classified as a resource if the oil can be successfully recovered. The remediation scheme described in this report is a technology that can be used to recover saleable oil from tank bottom waste pits, thus reducing the volume of waste.

The new process, called TaBoRR^{TM} (Tank Bottom Recovery and Remediation), remediates tank bottom wastes by removing the water and solids, thereby creating a saleable product (crude oil). The substantial costs of tank bottom waste disposal are avoided, and all wastes from the TaBoRR process can be disposed of in an economical and environmentally acceptable manner. Thus, the TaBoRR process provides major economic and environmental benefits to oil producers, while reducing their economic and environmental liabilities.

Preliminary bench scale experiments and simplified numerical simulations were performed by Satchwell and Johnson (1993), verifying the underlying theory of the new process. The TaBoRR process, based on thermal recovery and remediation of tank bottom wastes, consists of four steps: (1) preconditioning, (2) flashing, (3) distilling, and (4) pyrolyzing.

Preconditioning provides energy to the system by pressurizing and preheating the entire feed stream. Flashing of this stream is accomplished by an expansion valve, removing water and very light hydrocarbons present in the feed stream. Product oils are created by distilling the intermediates away from the solids and heavy hydrocarbons. The final step, pyrolyzing, removes any remaining liquid hydrocarbon. Detailed evaluation of the process in handling various waste sources requires further testing. This program is being conducted to provide for this optimization and development of the TaBoRR process.

Background

Crude oil is produced from subsurface formations and commonly contains solids and water. Crude oil purchasers monitor and limit the amount of basic sediment and water content in the crude oil. If established limits of BS&W are exceeded, purchasers either discount the price or refuse to accept custody of the crude oil. To avoid producing an unacceptable product, crude oil producers use every economical method to meet industry standards. BS&W limits are based on local conditions, practices, and contractual agreements (Bradley 1987). These BS&W limits vary between 0.2 to 3.0%. According to Bradley, crude oil purchasers can also limit the salt content of the crude oil.

Various techniques have been employed to remove the solids and water to meet BS&W limits. Produced water is removed from the hydrocarbon stream with skim tanks, separators, plate coalescers, skim piles, and gas flotation units. Solids are removed by use of gravity settling tanks, cyclones, centrifuges, and filters. Substantial quantities of oil are recovered using these methods, but a waste stream is created. Waste streams are composed of oil, sediments, and water, and they commonly exist in an emulsified phase.

Several other technologies have been developed to remediate tank bottom wastes. The most common method of treating these wastes is with filter presses (Rousseau 1992). With filter presses, the tank bottom waste is heated and injected through a filter medium to remove the solids. Water and oil are separated by gravity segregation and water is disposed of in an injection well, while oil is transported to a storage facility. One major problem associated with this process is the disposal of oil-contaminated solids and the filter medium. The contaminated solids must be cleaned before the filter material can be disposed of in a landfill. Costs associated with this technology include water disposal, solids disposal, and cleanup costs.

Project Objectives

The general objective is to develop information used for the successful deployment of WRI's patented TaBoRR technology (Western Research Institute 1994). To accomplish this, work is being conducted which includes: technology support, design and operation of a laboratory process unit, and numerical modeling and economic analysis. These tasks are described in the following sections.

Technology Support

The objectives of this task are: to gather emissions- and effluent-related information from the pilot plant, to provide assistance in the operation of the pilot plant, to characterize various tank bottom waste sources, and to develop material durability and compatibility data sets for use in the design and fabrication of subsequent TaBoRR plants.

Laboratory Process Unit

The objectives of this task are: to design and construct a laboratory unit capable of processing one to two barrels per day of tank bottom waste, to perform shakedown tests to eliminate any problems associated with the apparatus, to operate the laboratory unit with various sources of tank bottom wastes, and to provide a thorough sampling protocol and characterization of product and waste streams.

Process Modeling and Economic Analysis

The objectives of this task are: to develop a means of predicting process performance based on feedstock analysis, to define or identify appropriate test data required for adequate process simulation, and to perform an economic evaluation of the TaBoRR technology using feed stream variations, site-specific considerations, and plant operational variables.

EXPERIMENTAL METHODS AND PROCEDURES

The following section reviews the analytical methods and the experimental procedures used in this work. Since not all the work has been completed, more methods and new procedures may be implemented as needed.

Analytical Methods

Oil samples obtained from various sites were analyzed to determine several chemical and physical properties. The selection of the properties measured was based on those required to evaluate the tank bottom wastes. The properties included the BS&W, the distillate range, viscosity, and chlorine content of the oil.

The BS&W of the samples was determined using two methods. The first was to heat the sample in an oven set at 75°C (167°F) for one hour (to reduce the viscosity of the oil) followed by centrifugation. This procedure was repeated at least once to ensure complete separation of the oil, water, and solids. Centrifugation was conducted at 2000 rpm for one hour. The second method used to determine the BS&W of the samples involved azeotropic distillation with toluene. An aliquot of the sample was dissolved in toluene and then heated. The distillation procedure resulted in the isolation of the water in a receiver where its volume was measured. The resultant solvent/oil/solids mixture was then filtered through #42 filter paper to recover the solids. The tared filter paper was dried, and the weight of the solids determined. The solvent was removed from the solvent/oil solution using a rotary evaporator. The weight of the oil was determined by weighing the tared round-bottom flask.

The distillate ranges of the oil samples were determined using a gas chromatographic procedure that relies on the use of an external standard for quantification (Thomas et al. 1987). These analyses provided the initial and true boiling point curves for the crude oil present in the tank bottom wastes. For more information on the analyses performed, interested readers may refer to ASTM (1992) and EPA (1989) publications.

Experimental Procedures

Experimental procedures for the operation of the laboratory unit are being developed. A final protocol will be developed after the shakedown tests are performed. Major items that will be considered in the operational procedures include: system purging, system preheating, system pressurization, and product recovery temperature.

RESULTS AND DISCUSSION

The following sections contain the results and discussion of work performed to date. Included are discussions pertaining to the preliminary analyses of two sources of feed stream material, the design and construction of the laboratory demonstration unit, and modeling efforts.

The analyses of the feed stream materials consisted of determining the BS&W content of each feed material and the true boiling point curve for the crude oil. These data are used in the design of the process and in estimating product recoveries.

The laboratory unit was designed to simulate the 48m³ (300bbl/day) TaBoRR field unit. Thermal design calculations were estimated and verified using HYSIM^{TM} (Hyprotech 1993), a process simulator. This simulator has been used to estimate the heater and condenser sizes and will be used to simulate the process. The construction of the laboratory unit is approximately 95% complete, and initial shakedown tests will begin after leak tests are completed. The shakedown tests will be performed using water at ambient conditions to determine the flow characteristics of the apparatus. After these tests are completed, a second set of tests will be performed using hydraulic oil. During these tests, systems will be verified for operational readiness.

Feed Material Analyses

Two sources (Pit S and Pit BP) of tank bottom wastes were obtained from locations in Wyoming. These tank bottom wastes were analyzed and the results are given in Table 1. Two phases, water and oil, were visually present in the samples. With Pit S, the free water from the sample was not removed before the BS&W analysis was performed. In the Pit BP sample, the free water was removed with the use of a funnel before the BS&W analysis was performed. A true boiling point analysis was performed on the oil phase of each of the samples after all water was removed. The results of the true boiling point analyses are shown in Figures 1, 2, and 3.

Table 1. Analysis of Two Tank Bottom Waste Sources

	Pit S		Pit BP	
Sample #	S-1	S-2	BP-1	BP-2
Solids, wt %	9.0	8.5	1.8	1.0
Water, wt %	48.4	53.0	28.5	10.5
Oil, wt %	36.6	37.5	69.6	88.5
IBP ^a , °C (°F)	234 (453)	276 (529)	280 (536)	268 (515)

a - Initial Boiling Point

Figure 1. Distillation Curve for Pit S Using Azeotropic Distillation

Figure 2. Distillation Curve for Pit S Using Centrifuge Separation

Figure 3. Distillation Curve for Pit BP Using Azeotropic Distillation

These results reveal several interesting points. Figures 1 and 2 represent the distillation analysis of crude oil present in tank bottom wastes from a single source location. "S-1" designates the use of azeotropic distillation for sample preparation. "S-2" was used to designate that centrifuging was used for sample preparation. "A" and "B" represent a pit source material stored in a surface pit, and "C" and "D" represent the pit source material stored in tanks. Figure 3 represents the distillation curve from a different source location that was prepared using azeotropic distillation.

The results show that when azeotropic distillation was used to remove the water, a portion of the hydrocarbons was also removed. This fact is best explained by following the dotted lines at a temperature of 371°C (700°F). On Figure 1, which employed azeotropic distillation, the vaporized fraction is approximately 31.5 wt %. At the same temperature using the centrifuging technique for water removal, the vaporized portion is about 54.3 wt %. Based on this observation, the centrifuging technique for water removal is more appropriate than azeotropic distillation.

The final observation that can be made is that a portion of the hydrocarbons is missing in the tank-stored samples ("C" and "D") as compared to the pit samples ("A" and "B"). It appears that a portion of the hydrocarbons has been removed in both cases (Figures 1 and 2). One possible explanation for the difference is the vapor pressure of the hydrocarbon components.

The materials stored in the steel, above-ground storage tanks have been exposed to thermal cycles and higher temperatures than the samples stored in the pits. These higher temperatures provide energy for some of the hydrocarbon components to be vaporized. Since standard storage tanks are equipped with pressure relief venting systems, these hydrocarbons may have been vented to the atmosphere. It appears from this evidence that higher recoveries of hydrocarbons can be obtained from storage pits than from storage tanks that have been exposed to thermal cycles.

Description of the Laboratory Unit

A schematic of the laboratory unit is shown in Figure 4. As shown in this figure, tank bottom wastes flow into a Duriron EV-1 metering pump where the wastes are pressurized. This variable-speed pump is capable of discharging 1.8 to 18.1 kg (4 to 40 lb) per hour at a pressure in excess of 6.89 MP_A (1000 psi). The rate of feed is measured by a Toledo Digitol scale (MN 8510), which has a capacity of 544 kg (1200 lb).

The feed stream is pumped past a pressure relief valve and into a feed preheater that provides energy to elevate the feed stream temperature. Downstream, a Whitey letdown valve is installed to maintain the back pressure of the system. This letdown valve provides a means of breaking the emulsion by flashing the water overhead away from the hydrocarbons and solids. The Whitey valve is capable of handling pressures up to 41.4 MP_A (6000 psi) and temperatures as high as 316°C (600°F). The water that is vaporized downstream of the letdown valve is condensed and collected from the overhead stream.

Figure 4. Schematic of Experimental Apparatus

The liquid hydrocarbons and solids flow out the bottom of the flash tank and around the heating elements contained in the stripping units. The temperature to each of the four heating elements is controlled by a 18E-2-10 Payne power control, which is, in turn, controlled by a UDC 3000 Honeywell temperature controller. Power to each of the heating elements is regulated by monitoring its surface temperature. Thermocouples provide input to the temperature controllers. The heating elements in the stripping units operate at successively higher temperatures, distilling hydrocarbons away from the solids.

To provide an increase in the yield of distilled hydrocarbons, sweep gas is injected into the bottom of each heater. A Parker flow meter is installed to monitor the sweep gas volume injected into the system. Flow to each stripping unit is monitored by a Brooks rotometer, and the condensible hydrocarbons are condensed as product. The hydrocarbons are condensed in an SFF-302-HY-1P Young heat exchanger capable of withstanding temperatures up to 204°C (400°F) and pressures as high as 1.03 MPa (150 psi). The heat exchangers are attached to a CFT-300 NESLAB recirculating chiller rated with a cooling capacity of 10.65 kW, more than 30% in excess of the energy supplied to the system.

Since sweep gas is not injected into the flash tank, gas flow rates are monitored from the flash tank using a GCA/Precision Scientific wet test meter. Any noncondensable gas streams (including the sweep gas) are monitored and analyzed by a 5840 Hewlett-Packard gas chromatograph that contains a Chromosorb 102 column with the output directed to an 18850A Hewlett-Packard GC terminal.

Design and Construction of the Laboratory Unit

The laboratory unit was designed by scaling down the 48m³/day (300 bbl/day) field unit. Scaling factors from Perry (1984) were consulted. Minor modifications were employed in this apparatus, including using direct electrical heating instead of indirect hot gas heating, eliminating countercurrent heat exchangers to increase the energy efficiency of the process, and treating the single field stripping unit as four separate stages in the laboratory unit.

The important factors considered in the design of the TaBoRR laboratory unit were the mass and heat transfer processes and the materials of construction. Since tank bottom wastes can contain corrosive materials, stainless steel was used.

The major items that required sizing were the feed preheater, the flash tank, and the four heater units of the stripper. The design parameters for each of these units are given in Table 2. The final design criterion for the heating elements was that the heating density be less than 45 W/cm² (7 W/in²). This low heating density prevents the coking of the hydrocarbons on the heating elements. These process components are shown in Figures 5, 6, and 7.

Table 2. Design Parameters for Laboratory Unit Components

Component	ΔT	L/D	Flow ^a	Heat Requirement ^b
	°C (°F)	---	kg/hr (lb/hr)	kW
Feed Preheater	204 (400)	16.0	6.6 (14.6)	2.5
Flash Tank	227 (200)	7.3	6.6 (14.6)	----
Stripper Unit	343 (250)	10.7	6.6 (14.6)	1.65

a - Based on water

b - Based on approximately 30% heat loss

Figure 5 represents the feed preheater. The 122-cm-long (48-in.) Chromalox flanged immersion heater was housed in a 132-cm-long (52-in), 7.6-cm (3-in.) schedule 80 stainless steel pipe. For the fluid inlets and outlets on all vessels, 2.54-cm (1-in.) schedule 80 couplings were used.

Figure 6 illustrates the flash tank. The three-phase waste stream (water vapor, liquid hydrocarbons, and solids) enters through the inlet in the side of the flash tank. The offset of the inlet was created by adding 15.2 cm (6 in.) of demister screen at the top of the flash tank outlet. The liquid outlet was located at the bottom of the vessel. The vessel dimensions of 55.9 cm (22 in.) long and 7.6 cm (3 in.) in diameter were based on a maximum gas velocity that would still allow for the separation of liquid mist from a gas phase. This maximum velocity was computed to be 1.16 m/s (3.8 ft/sec). The demister screen was added to ensure that liquid hydrocarbon would not be entrained in the overhead stream.

Figure 5. The Feed Preheater

Figure 6. The Flash Tank

Note: All Dimensions in Centimeters

Figure 7. A Stripping Unit

Process Modeling

One of the four stripping units is shown in Figure 7. In the field unit, the entire stripping unit is one vessel with four baffled sections. In the laboratory unit, four separate components were used to simulate the field stripping unit. This was required due to the size of the heating elements. The 81.28-cm-long (32-in.) heating element was installed in the bottom of an 20.32-cm (8-in.) schedule 40 stainless steel pipe equipped with end plates. A 7.62-cm (3-in.) pipe was installed on an end plate to allow for the connection of a heating element to the vessel by means of a flange. Sweep gas was supplied from a manifold and injected at the bottom of the vessel through a 0.635-cm (0.25-in.) stainless steel tube. Distilled hydrocarbons were allowed to exit with the sweep gas from the top of the vessel through a 2.54-cm (1-in.) coupling to the condenser and product collection system.

Liquids entered the stripping unit through a 2.54-cm (1-in.) collar mounted on the 7.62-cm (3-in.) pipe. The 2.54-cm (1-in.) outlet was installed 2.54 cm (1 in.) above the centerline of the 20.32-cm (8-in.) pipe. This outlet location provided a means of maintaining liquid level above the heating elements. Furthermore, the inlet and outlet locations provided for the liquid seal in each vessel, which prevented gases from flowing from one vessel to another.

Several other components required fabrication. These components, shown in Figure 4, were: the accumulators, the sweep gas manifold, the condenser manifold, and the non-condensable gas manifold. Other safety items included the pressure relief valve and check valve located directly downstream from the feed pump. This system provided a means of discharging over-pressurized liquid and prevented the escape of hot liquids from the preheater. Shown in Figure 4 are check valves on each sweep gas line entering the heating elements of the stripping units. These check valves provided a means of preventing hot liquids from entering the sweep gas manifold or plugging off the sweep gas sparger located in the stripping unit.

A proposed process model, shown in Figure 8, has been developed using HYSIM. Minor modifications to the process layout shown in Figure 4 were required for modeling purposes. These modifications included the installation of condensers upstream of the accumulators and the reconfiguration of the stripping units. In the laboratory process, the stripping units contain sweep gas sparger, heater, and vapor outlet. Thus, modeling of the stripping process required three steps. These steps, as shown in Figure 8, were to mix sweep gas with the hydrocarbons, to heat the mixture in a heater, and to separate the liquid from the gas phase in a separation unit.

Figure 8. TaBoRR Process Model

Some preliminary modeling has been performed to confirm the heater and condenser sizing of the laboratory unit. However, these results will not be reported or published until confirmed by experimental data.

CONCLUSIONS

More samples of tank bottom wastes are being acquired for experimental purposes. These new samples will be analyzed to complete the characterization of tank bottom wastes. The laboratory unit is being constructed and is approximately 95% complete. When completed, shakedown tests will be performed using water and clean oil before testing tank bottom wastes. After experimental results are compiled, numerical modeling efforts will progress.

Work yet to be completed includes: providing technology support to the field demonstration unit, finalizing construction and operation of the laboratory unit, and finalizing process and economic modeling of the TaBoRR process.

DISCLAIMER

Mention of specific brand names or models of equipment is for information only and does not imply endorsement of any particular brand.

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