**FIELD TESTING OF THE TABORR®
(TANK BOTTOM RECOVERY AND REMEDIATION)
PROCESS USING THE ASPHALT AND DRY BOTTOMS
CONFIGURATIONS**

Topical Report

Reporting Period March 1996 – March 1997

**By
Robert M. Satchwell
Vijay K. Sethi
Lyle A. Johnson Jr.
Lee E. Brecher**

April 1997

**Work Performed Under
DE-FC21-93MC30127 Task 20**

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

**By
Western Research Institute
Laramie, Wyoming**

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agencies thereof, nor any of its employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed or represents that its use would not infringe on privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES	iv
LIST OF TABLES	iv
EXECUTIVE SUMMARY	v
INTRODUCTION	1
Background	1
Anticipated Benefits From This Program	2
PROCESS DESCRIPTION	2
Conceptual Description	2
Current Configuration	3
Pyrolyzer Description	4
FIRST YEAR PROGRAM DESCRIPTION	5
Objectives	5
Results	6
Plant Assembly	6
Equipment Operations	7
Product Analyses	7
Pyrolyzer Design	9
Permitting	9
Road Base Tests	10
FUTURE WORK	10
REFERENCES	13

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Inversion Characteristics of Emulsions	1
2	Conceptual Schematic of the TaBoRR Process.....	3
3	Current Process Configuration	4
4	Pyrolyzer Flow Schematic	5
5	TaBoRR Plant Layout.....	6
6	Boiling Point Curves of Materials Created During Shakedown Operations	8

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Feed Material and Product Oil Comparisons.....	9

EXECUTIVE SUMMARY

Oil producers are held accountable by pipeline companies for basic sediment and water (BS&W) levels in crude oil. A major cost associated with oil production is the disposal of the waste streams that are created. The costs associated with disposal range from \$7 to \$20 per barrel. In environmentally sensitive areas, this disposal cost can be as high as \$400 per barrel. Furthermore, the oil producers assume the environmental liability for the disposal of these waste streams.

The TaBoRR® (Tank Bottom Recovery and Remediation) process being developed at Western Research Institute (WRI) offers an alternative to current disposal methods. The TaBoRR process is designed to: (1) process these wastes, (2) provide a cost saving, and (3) limit or reduce the environmental liability of the producers. This process removes the water through evaporation, eliminating water disposal costs, creates a salable crude oil that has been valued at or above the current market price for sweet West-Texas intermediate crude, and reduces the solids to a benign state for disposal at a landfill.

This report presents the background information associated with this program, a detailed description of the process, and the work that has been completed during the first year of this program. The plant assembly, unit operations, product analyses of the materials created during operations, the pyrolyzer design, and permitting of the process in Wyoming are described.

Also discussed in the report is the future work required to take this process to commercialization. Future work discussed includes shakedown and operation of the pyrolyzer, control systems and plant automation, integrated operations, equipment reliability, effluent sample analysis, and long-term testing of the process.

INTRODUCTION

The first year of the TaBoRR® (Tank Bottom Recovery and Remediation) program, which was structured to field test the TaBoRR process, has been completed. This report provides background information related to the program, anticipated benefits, TaBoRR process description, program objectives and results, and the future work required.

Background

Tank bottoms wastes are emulsions that can be distinguished as two basic types: oil-in-water (O/W) and water-in-oil (W/O). The emulsions encountered in the petroleum industry are composed of oil, water, and an emulsifying agent. This emulsifying agent can be inorganic electrolytes, surfactants, and/or fine solids. According to Grace (1992), emulsions formed in the petroleum industry are predominantly W/O emulsions in which the oil is the continuous or external phase, and dispersed water droplets form the dispersed or internal phase. The types of emulsions (O/W and W/O) and the viscosity effect are depicted in Figure 1 (Becher 1966). This figure illustrates that inversion occurs at an oil fraction of 0.74. The discontinuity in viscosity represents the inversion point. Schramm (1992) points out that W/O emulsions can exist with higher internal fractions; however, inversion usually occurs when the internal fraction is close to 0.74. Factors that influence the inversion point are the type and concentration of emulsifiers, as well as physical influences such as temperature and mechanical shear.

Figure 1. Inversion Characteristics of Emulsions

Anticipated Benefits From This Program

Within the petroleum industry, emulsions are associated with production, transportation, and refining. The areas of concern for the industry regarding emulsions are product quality, operability issues, and the associated economic and environmental impacts. Producers must meet pipeline specifications. Generally, the oil may not contain more than 0.5% BS&W (basic sediment and water), although some pipelines have more stringent specifications. Failure of producers to meet pipeline specifications will result in increased fees. Failure over a long period of time will result in the pipeline company refusing to accept produced oil. Pipeline companies have implemented BS&W levels to minimize corrosion and reduce the amount of waste transported to refineries. Refineries have implemented BS&W levels for pipelines in an effort to protect equipment and avoid elevated operating costs. In all cases, the producer is forced to minimize the BS&W content in produced crude.

Various techniques have been employed to treat these emulsions. Methods that have been employed include chemical, mechanical, thermal, and electrical techniques. These techniques are expensive and/or ineffective in treating these emulsions. Based on these facts, analyses and bench-scale processing were performed by Satchwell and Johnson (1993). This work provided the basis for the TaBoRR process. The use of this technology will reduce or eliminate the problems associated with emulsions.

PROCESS DESCRIPTION

Conceptual Description

A schematic of the TaBoRR concept is shown in Figure 2. As depicted in this figure, the tank bottoms are heated under pressure and flashed at atmospheric conditions. Flashing provides a means of breaking the emulsion and removing the water phase. Water-free hydrocarbons are distilled away from the solids in a stripping operation and recovered as product. The remaining solids and hydrocarbons are coked and cracked in the pyrolyzer. Product is recovered as vapors in the product recovery system, and solids are discharged with a carbon coating.

Figure 2. Conceptual Schematic of the TaBoRR Process

Current Configuration

The TaBoRR process has undergone considerable modifications and changes from its conception. Figure 3 represents the final configuration of the equipment for the flash and stripper operations only. The process is designed to receive tank bottoms from the feed tank, which are preheated by a pair of heat exchangers. System pressure is maintained by the use of the flash valve. The second heat exchanger (HX-2) was installed downstream of the HX-1 to improve heat transfer efficiency and provide an improved control strategy. From the flash valve, the energy added to the system provides heat to vaporize water present in the feed material. This water exits the flash tank and is evaporated in the flare. The remaining hydrocarbons and solids are pumped into the stripper, where hydrocarbons are distilled overhead. Distillation in the stripper is improved by the bubbling of natural gas (sweep gas) into the stripper. This overhead stream is cooled, and the condensed hydrocarbons and sweep gas are separated. The hydrocarbons are collected as product, and the sweep gas is burned in the flare. The remaining hydrocarbons and solids (stripper bottoms) exit the stripper and are pumped into storage tanks. The storage tanks are used to collect material until the pyrolyzer is installed.

Figure 3. Current Process Configuration

Pyrolyzer Description

The pyrolyzer flow schematic is shown as Figure 4. The pyrolyzer is designed to take material either from the stripper bottom storage tank or directly from the discharge exiting the stripper. The stripper bottoms are subjected to indirect heat that is supplied by combustion gases created by a burner. This material is pumped into the pyrolyzer, where carbonized solids and hydrocarbons are produced through coking and cracking reactions. This vaporized hydrocarbon stream is condensed and separated as product oil and noncondensable gas. The product oil is pumped to a product oil storage tank, and the gas is flared. During this reporting period, the pyrolyzer was designed and fabricated.

Figure 4. Pyrolyzer Flow Schematic

FIRST-YEAR PROGRAM DESCRIPTION

Objectives

The objectives for the first year were to:

1. Perform modifications to the field demonstration unit to allow for handling higher water concentrations and larger solid sizes present in the feed material,
2. Test and operate the unit using a variety of feed materials,
3. Determine the feasibility of using the stripper bottoms as a road base material,
4. Perform modifications to the process to convert the heavy ends (bottoms) exiting the stripper into solid material,
5. Evaluate the use of the gaseous hydrocarbons as a fuel source for the process, and
6. Test and operate the unit to ensure environmental compliance and verify process economics.

Results

Plant Assembly

The 300-barrel-per-day demonstration plant was assembled at WRI's Advanced Technology Center. A 30-day operational wavier was obtained from the Wyoming Department of Environmental Quality (WDEQ) to operate the unit. This wavier was granted, allowing WRI time to accumulate environmental data pertaining to the permitting process. A copy of this wavier is available for review at WRI. Tank pads and tankage were installed to store feed materials, stripper bottoms, and product oil. The equipment and tankage layout is shown in Figure 5.

Figure 5. TaBoRR Plant Layout

This figure represents the equipment used for an integrated operation, but does not illustrate the associated plumbing and electrical systems. The pads containing the equipment are approximately 90 ft wide by 90 ft long. Each tank pad is approximately 40 ft wide by 50 ft long. Each pad was constructed from bottom to top with a 6-inch sand pad, a hydrocarbon and ultra-violet resistant 20-mil liner, and a 6-inch gravel top cover. After each pad was constructed, containment berms were erected as part of a spill prevention plan. This figure also illustrates the proposed layout for the pyrolyzer system. This system includes the pyrolyzer skid, pyrolyzer burner skid, and the product recovery skid (chiller skid). A winterization program was initiated to

allow shakedown operations to commence during the cold months in Wyoming. This program included the installation of tank heaters and heat tracing and the insulation of the decant tank and all fluid carrying lines.

Equipment Operations

Approximately 340 barrels of feed material were received from Pease Oilfield Equipment Company. This material was sampled and analyzed at WRI. The results of analyses indicated that the feed material contained 0.3 wt. % solids and approximately 20 wt. % water. This material was used for debugging plant equipment under cold flow conditions. These cold flow conditions were used to leak-check the high-pressure components of the system.

Hot plant shakedown operations were initiated during early October. Shakedown operations were staged for each process step. The first process step tested was the flash step. The flash step and control system worked very well. The system was originally configured to condense the flash overheads; however, the costs and capital equipment requirements, as well as the environmental consequences associated with condensing the water phase, were inappropriate. The flash tank was modified to direct the overheads to the flare to eliminate these issues.

Integrated plant testing of the flash and stripper steps was begun in October 1996. Early operations showed that the product recovery system was not operating as expected. The original system arrangement employed a blower to provide suction of the distilled stripper vapors and a heat exchanger (HX-2) for the recovery of heat from the distilled stripper vapors to the feed material. This original configuration was unpredictable from a control standpoint. The distilled vapors did not supply a continuous heat flux to the feed material. This discontinuous heat flux created severe oscillations and control problems in HX-1, which supplied heat to maintain flash conditions. The blower was removed from the system because it did not allow positive pressure to be maintained in the stripper. The oscillatory behavior was eliminated by removing HX-2 and installing it in the current configuration, as shown in Figure 3.

Product Analyses

The results of testing the Pease Oilfield material are presented in Figure 6. This figure represents the feed, product, and stripper bottoms boiling point curves. During this operation, approximately 47.4 vol. % recovery was achieved. An overall recovery of 38 vol. % was obtained during shakedown operations using this material. Individual recovery rates between 40 to 65 vol. % were achieved. These results indicated that as the average operating temperature was increased, recovery increased. These results also indicated that an optimum sweep gas rate exists and would result in maximized recovery at a particular stripper operating temperature.

Figure 6. Boiling Point Curves of Materials Created During Shakedown Operations

Product analyses were performed by a refinery laboratory. The results of these analyses are given in Table 1. Table 1 represents a comparison of the feed material and the product oil. The process created an upgraded product. This fact is evident in the increase in the oil gravity or reduction in specific gravity, the reduction in sulfur, chlorides, and BS&W, the reduction in viscosity, and the small value given for Ramsbottom carbon.

The final modification implemented during this reporting period was the installation of a continuous pump that injected flash bottoms into the stripper. The original configuration used a pump that operated on floats installed in the flash tank. At high level, this cyclic pump discharged approximately 15 gallons of flash bottoms into the stripper at a rate of approximately 10 gallons per minute. These discharge surges created a cyclic temperature phenomenon in the stripper. This surging of material allowed for the carryover of material to the stripper bottoms outlet. This data is evident in the boiling point curve of the stripper bottoms shown in Figure 6. The implementation of the continuous pumping system stabilized the temperature gradients and increased hydrocarbon recoveries.

Table 1. Feed Material and Product Oil Comparisons

PARAMETER	FEED MATERIAL	PRODUCT OIL
Oil Gravity, degrees API	20.0	25.7
Specific Gravity	0.934	0.900
Sulfur Content, wt %	0.25	0.17
Basic Nitrogen, ppm	–	113
Total Chlorides, ppm	15.1	7
BS&W, wt %	20.3	0.1
Vanadium, ppm	–	< 1
Nickel, ppm	–	< 1
Viscosity @ 40°C, cSt	175	10.02
Ramsbottom Carbon, %	–	0.19
SFC		
Saturates	–	67.0
Mono-Aromatics	–	19.6
Di-Aromatics	–	7.7
Poly-Aromatics	–	4.6
Polars	–	0.9

Pyrolyzer Design

The pyrolyzer design has been completed. This reactor consists of twin 16-inch screws that are indirectly heated using a fluid bed. The pyrolyzer has been thermally designed to handle feed rates between 75 and 225 barrels per day. Heat is supplied to the pyrolyzer by a natural gas burner system. Fluid bed design parameters were obtained from Kunii and Levenspiel (1969). The functions of the twin screws are to: (1) transport solid material to the discharge port, (2) assist in mixing the material, and (3) provide self-cleaning. These functions increase the amount of indirect heating that can be supplied to the material and allow the reactions to occur in a reducing environment inside the screws. Variable-speed motors were installed to provide variable residence time. Rotary valves were installed to maintain a gas seal at the solids outlet port. Hydrocarbon vapors are vented from the top of the screw. Ports have been installed to provide a way of injecting sweep gas into the screw section. Shakedown of this reactor will be completed at a later date.

Permitting

During this reporting period, permitting for operations in Wyoming continued. Condensed versions of these applications and permits are available for review at WRI upon request. These documents contain the permit application and permit from the Air Quality Division of WDEQ and the permit application for the Solids and Hazardous Waste Division of WDEQ. The finalized permit from the Solids and Hazardous Waste Division is expected to be received in the near future.

Road Base Tests

The feasibility of using the stripper bottoms has been delayed. The work to complete this task was originally scheduled to occur during operations at the Navel Petroleum Reserve #3 (NPR-3). However, WDEQ ruled that the tests of the stripper bottoms material would only be valid if created from the 300-barrel-per-day unit. Personnel at NPR-3 would not tank and assume this liability of stored material, and an impasse was created. WRI personnel are working on solutions to remedy this situation.

FUTURE WORK

A substantial amount of work has yet to be completed for the commercial deployment of the TaBoRR technology. This work includes implementation, testing, and integration of the pyrolysis unit into the existing plant; long-term plant operations employing optimum plant configurations for diverse feed stocks of differing compositions; and acquisition, evaluation, and compilation of data required for siting and permitting. The overall goal of the proposed work is to demonstrate, through long-term testing, the commercial viability of the TaBoRR technology for various feed stocks. Specific objectives to achieve the overall goal are: to procure, test and integrate a pyrolysis unit; to define the maximum limits for solids and water content in the materials that can be economically processed in various configurations of the technology; to acquire pertinent data for siting and permitting; to establish component reliability; and to develop process control strategies for full automation of commercial plants.

A 150-barrel-per-day pyrolyzer based on an indirectly heated twin-screw reactor concept has been designed and will be completed and delivered during 1997. Since feed materials ranging in water content from 0 to 70% might be encountered, the processing capacity of the pyrolyzer will be dependent on the feed material composition. Provisions will be made for handling feed materials with diverse physical properties and handling characteristics. The current configuration is based on natural gas fuel; however, economic analyses will determine if the noncondensable gases created from the pyrolyzer can be used as a fuel source. Provisions will also be made so that the pyrolyzer can be used as a stand-alone unit for processing some of the tank bottoms that do not require either the flash or the stripper operations.

Peripheral equipment and controls will be designed and assembled at WRI to allow for the modifications as dictated by the feed material composition, properties and processing needs. The peripheral equipment and controls include, but are not limited to, a burner as a hot-gas source, condenser, product separator, electrical components, instrumentation, and control equipment.

In the fully integrated configuration, the pyrolyzer will process stripper bottoms, converting them into a carbon-rich landfillable solid material. Any gases produced will either be flared or used as process fuel. Liquids produced will be blended with the salable product from the rest of the TaBoRR plant. In the stand-alone configuration, the pyrolyzer will operate with feed materials that are either high in solids concentration (e.g., Alyeska material) or are difficult to process using the flash/stripper configuration of the TaBoRR technology. In this configuration, the pyrolyzer will be tested and operated at WRI's Advanced Technology Center. In the stand-alone configuration, it is envisioned that following a brief testing at WRI, the pyrolyzer will be moved to the host site for extended demonstration.

Feed materials from various sources will be processed according to their composition and other physical properties, using various plant configurations to develop optimum processing schemes. For example, feed materials containing high water content (greater than 17%, a limitation of the flash operation based on pressure and temperature limits of the equipment) can only be handled if multiple flash steps are incorporated into the plant configuration. It is also possible, however, that some of these feed materials might be processed using a decanting step after a preliminary, relatively mild flash operation and thus reduce the operating and processing costs of recovering hydrocarbons. Processing a feed material with these concentrations will allow for the determination of equipment operating constraints.

The effluent streams created by the process will be sampled and analyzed for all different feed materials and processing configurations. The streams that will be analyzed include: the noncondensable gas stream created from the stripper and pyrolyzer sweep gas, the product oil stream created by the stripper, the product oil stream created by the pyrolyzer, the benign solids created by the pyrolyzer, and the combustion gas stream created by the burner. This information will be used in the permitting and licensing of the process through the appropriate regulatory agencies. It will also provide mass and energy balances as well as analyses for emission streams such as noncondensable gaseous stream burner in the flare or the solids created from the pyrolyzer.

The reliability of all components can only be determined through continuous operation of the plant. During the coming year, it is the intent to process at least 10,000 barrels of material, which will provide approximately 50 to 75 days of processing conditions. Durability and reliability of critical components, such as valves and pumps, will be monitored. Erosion, corrosion, and wear issues will be addressed by periodic inspection of the vessel and component internals. If deemed necessary based on performance records, a testing program will be implemented to identify compatible materials and/or design changes. For example, during the first year of this program, a wear issue concerning the flash valve was identified. A solution has been

determined and is being incorporated into operations for the second year of this program. Other issues that will be addressed include material cost and replacement versus material type and thermal cycling and fatigue of process equipment.

Preliminary economic analyses have shown that the profitability of the technology is associated with labor costs. To address and offset labor costs, plant automation is required. However, before plant automation can be addressed, a cause/effect/response database from continuous plant operations must be developed. The development of this database will proceed concurrently with the other tasks. Also to be included in this database are any safety issues that could arise from operation of the plant. After sufficient data is collected, automation will be incorporated. During the course of this project, various subsystems will be automated as an adequate cause/response database is developed.

REFERENCES

- Becher, P., 1966, "Emulsions: Theory and Practice," 2nd Ed., ACS Monograph Series 162, American Chemical Society, Washington, DC.
- Grace, Richard, 1992, "Commercial Emulsion Breaking," *Emulsions: Fundamentals and Applications in the Petroleum Industry*, Advances in Chemistry Series 231, American Chemical Society, Washington, DC.
- Kunii, Daizo, and Levenspiel, Octave, 1969, *Fluidization Engineering*, Krieger Publishing Company, Inc., Malabar, FL.
- Satchwell, Robert M., and Johnson, Lyle A., 1993, "Process Development for Treatment of Tank Bottom Wastes," WRI Report: WRI-93-R005, Western Research Institute, Laramie, WY.
- Schramm, Laurier L., 1992, "Commercial Emulsion Breaking," *Emulsions: Fundamentals and Applications in the Petroleum Industry*, Advances in Chemistry Series 231, American Chemical Society, Washington, DC.