IN SITU VITRIFICATION: A LARGE-SCALE PROTOTYPE FOR IMMOBILIZING RADIOACTIVELY CONTAMINATED SOIL

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ABSTRACT

Pacific Northwest Laboratory is developing the technology of in situ vitrification, a thermal treatment process for immobilizing radioactively contaminated soil. A permanent remedial action, the process incorporates radionuclides into a glass and crystalline form. The transportable process consists of an electrical power system to vitrify the soil, a hood to contain gaseous effluents, an off-gas treatment system and cooling system, and a process control station. Large-scale testing of the in situ vitrification process is currently underway.

INTRODUCTION

In situ vitrification is a new process being developed for the Department of Energy at the Pacific Northwest Laboratory to immobilize radioactively contaminated soil. This thermal treatment process converts contaminated soil into a chemically inert and stable glass crystalline product. The product's analogue, obsidian, exhibits such extremely small hydration rates that the in situ vitrified waste form is expected to have an effective lifetime of over one million years.

Pacific Northwest Laboratory began developing in situ vitrification (ISV) technology in 1980. Since that time, 36 engineering and pilot-scale tests have been conducted under a variety of conditions and with various waste types, proving the feasibility of the process. The successful results of these tests led to the design, fabrication, and testing of a large-scale prototype.

The large-scale process equipment has been fabricated and installed, and testing is currently underway with nonradioactive mockups of large-scale contaminated sites. This paper presents an in-depth description of the large-scale process and its capabilities. Pacific Northwest Laboratory recognizes that ISV is not the solution to all radioactive management problems, but judiciously applied, ISV can offer technical and economic improvement to state-of-the-art remedial action technology.

PROCESS DESCRIPTION

The ISV process is shown in Fig. 1; the large-scale process equipment in Fig. 2. The process immobilizes contaminated soil and isolates it from the surrounding environment. Controlled electrical power is distributed to the electrodes, and special equipment contains and treats the gaseous effluents. The process equipment required to perform these functions can be described most easily by dividing it into six major components:

- electrical power supply
- off-gas hood
- off-gas treatment system
- glycol cooling system
- process control station
- off-gas support equipment.

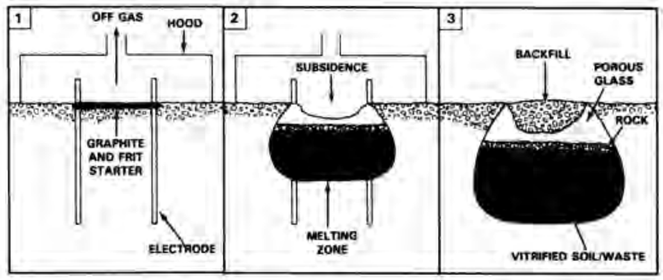

Fig. 1. The in situ vitrification process.

Except for the off-gas hood, all the components are contained in three transportable trailers shown in Fig. 3. They consist of an off-gas trailer, a process control trailer, and a support trailer. All three trailers are mounted on wheels sufficient to accommodate a move to any site over a compacted ground surface. The off-gas hood and off-gas line, which are installed on the site for collection of gaseous effluents, are dismantled and placed on a flat-bed trailer for transport. The effluents exhausted from the hood are cooled and treated in the off-gas treatment system. The entire process is monitored and controlled from the process control station.

DESCRIPTION OF TRAILERS

The off-gas trailer is enclosed and contains an internal containment module, which houses and isolates the off-gas treatment equipment. The containment module is a large glovebox constructed primarily of stainless steel. It isolates operators from processing equipment, and protects them from being contaminated in the event of an off-normal condition such as a leak in pressurized piping. The containment module is vented by two independent blowers operated by either primary or emergency power and has high-efficiency particulate air (HEPA) filters at the entrance and exit. A slightly negative pressure (1 cm of water) is maintained within the containment module relative to the aisles. The off-gas trailer measures 3.6 m wide x 18.3 m long and weighs 55,000 kg. The maximum height of the off-gas trailer *including the undercarriage* is 4.32 m.

The process control trailer is a covered van with standard highway dimensions measuring 2.4 m x 13.7 m x 4.08 m high. All process monitoring operations are performed from the process control station that is

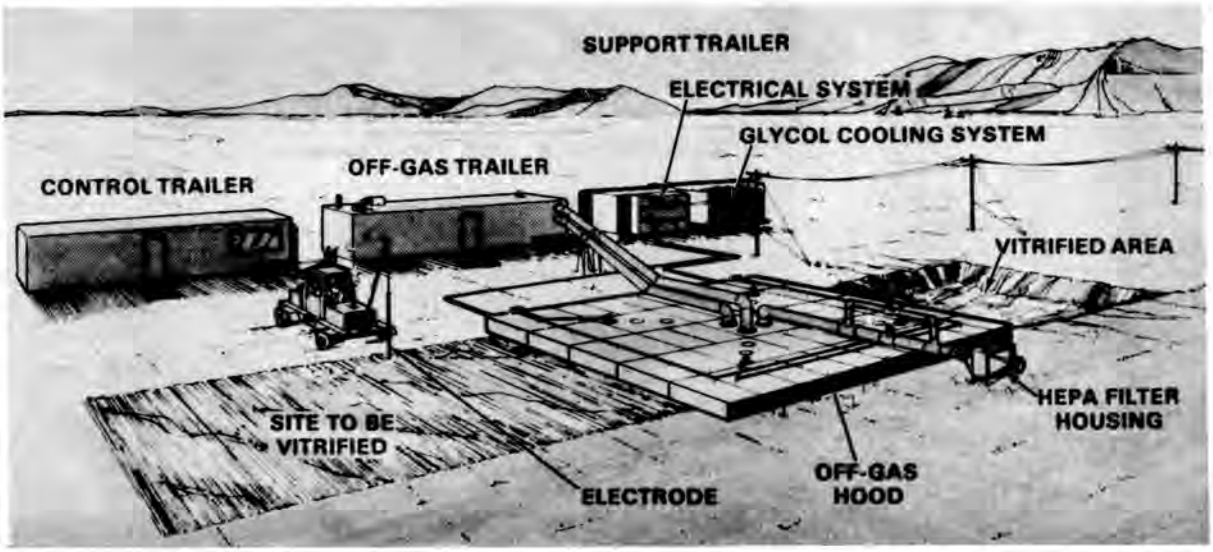

Fig. 2. Large-scale process equipment for in situ vitrification.

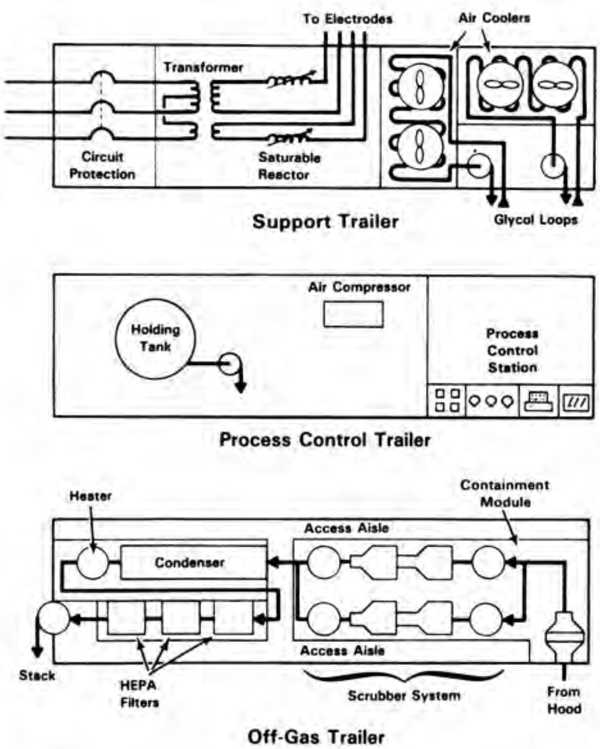

Fig. 3. Process trailers for large-scale in situ vitrification.

located in this trailer. In addition, the trailer houses miscellaneous support equipment of the off-gas system. A soundproof wall exists between the support equipment and the process control equipment. Like the off-gas trailer, the control trailer is constructed of aluminum and painted steel walls that are insulated with a noncombustible material.

The support trailer houses the electrical power supply and glycol cooling system. The support trailer, a standard flat-bed trailer, measures 2.6 m x 14.6 m x 1.40 m high. Overall height with equipment mounted on the trailer is 4.1 m. The trailer's total load capacity is 34,100 kg.

PROCESS EQUIPMENT

The six major components of the large-scale ISV process--electrical power supply, off-gas hood, off-gas treatment system, glycol cooling system, process control station, and off-gas support equipment--are integrated to provide a flexible system capable of treating various contaminated soils and buried wastes. A description of individual features and capabilities of the major components follows.

Electrical Power Supply

The electrical power supply provides and regulates power to the electrodes. It is composed of a 3750-kVA power supply and 15-kV circuit protection switchgear.

Power is supplied to the electrodes from the 3750-kVA Scott-Tee power supply, which provides 14 different voltage taps. A Scott-Tee transformer converts three-phase power to a balanced two-phase system. Voltages are achievable from 4160 V to 440 V at an amperage from 450 A to 4000 A per electrode pair. A saturable reactor in series with the load controls power to the electrodes between voltage taps for maximum efficiency, safety, and control.

Power to the 3750-kVA power supply can be interrupted by the 15-kV circuit protection switchgear located adjacent to the power supply. Power can be shut down at the switchgear or remotely from the control panel. Power interruption to the electrode power supply will not interfere with power to the off-gas equipment. Outdoor electrical services are provided for air sampling and other support equipment. Power for all lighting, processing equipment and communication services is provided by circuits that are independent from the electrode power supply.

Off-Gas Hood

The hood contains the gaseous effluents from the process, provides a confined area for combustion, and directs the effluents to the off-gas system. Because it supports the electrodes via insulators, the hood is grounded. It measures 12 m x 12 m x 1.8 m high and is supported by joists. A lifting device is located at each corner so that the assembled hood can be repositioned to a new nearby setting. The hood is constructed of 16-gauge stainless steel panels, bolted and gasketed together in a manner that relieves stresses due to nonuniform thermal expansion. The hood is sealed to the ground by a high-temperature flexible skirt, which is bolted around the hood's perimeter and covered with soil. The hood is connected to the off-gas trailer by two 40-cm off-gas lines (two are provided for redundancy). A 30-cm combustion air inlet and a pressure relief valve with high-temperature HEPA filters are annexed to the hood. The HEPA filters provide off-gas decontamination of particulates in the event of pressurization and backflow. The combustion air and off-gas flows are separated by a heat shield that extends below the hood's ceiling. The heat shield effectively directs combustion air toward the surface of the vitrification zone and keeps the hood-skin temperatures within the 550°C design criteria.

Off-Gas Treatment System

The off-gas treatment system (Fig. 4) cools, scrubs, and filters the gaseous effluents exhausted from the hood. Its primary components include: a gas cooler, two wet scrubber systems (tandem nozzle scrubbers and quenchers), two heat exchangers, two process scrub tanks, two scrub solution pumps, a condenser, three mist eliminators (vane separators), a heater, a HEPA filter assembly, and a blower system.

Due to the additional heat load from high concentrations of buried solid and liquid organic combustibles, off gases entering the off-gas trailer can be expected to reach a maximum temperature of 750°C. To keep the size of the heat exchange equipment manageable for a transportable facility, a gas cooler is provided to remove a major portion of the heat load from the off gases before quenching. The gas cooler is a finned air-to-glycol heat exchanger. It is capable of transferring 1100 kW from the off gas to a glycol loop, cooling the gases to 300°C. The gas cooler can be bypassed by operating three 40-cm pneumatic-actuated butterfly valves.

From the gas cooler, the off gas is split and directed into two wet scrubber systems operating in parallel. Two scrubbing systems provide an operating flow range between 30 and 104 standard m^3/min. At flows less than 60 standard m^3/min, only one system will operate. The dual scrub system also provides redundancy in the event of single component failure. Each system is composed of a quench tower, a tandem nozzle scrubber, and a vane separator. The quencher reduces the gas temperature from 300 to 66°C, and provides some scrubbing action to remove 90% of particles and semivolatile radionuclides. The tandem nozzle scrubber's primary functions are to remove an additional 90% of particles that are 0.5-micron dia and larger, condense remaining semivolatile components, and provide additional cooling of the off gas. The van separator that follows each tandem nozzle scrubber removes all droplets 12 microns and larger.

The scrub solution injected into the quenchers and tandem nozzle scrubbers is cooled through two single-pass heat exchangers before being returned to the process scrub tanks. Each heat exchanger can remove 120 kW from the scrub solution and transfer each 120 kW of heat to the glycol solution.

Two independent scrub pumps recirculate the scrub solution from the process tanks to the wet scrubbers. Each pump can deliver 510 L/min with a maximum deliverable pressure of 14.5 KPA. In addition, the scrub pumps can flush out the gas cooler and off-gas piping that are not wetted by the wet scrubbers.

Following the scrubber systems, the off gas is recombined and cooled. A condenser and mist eliminator provide additional decontamination of the off gas by condensing it and removing water droplets. The condenser transfers 320 kW from the off gas into flowing glycol. The mist eliminator, a vane separator, removes droplets 12 microns and larger. Both the condenser and mist eliminator are rated at 104 standard m^3/min at the outlet.

After the condenser/mist eliminator, the gases flow to the heater and HEPA filters. To prevent moisture condensation in the HEPA filters, the off gas is reheated by the heater. The heater is capable of raising the off-gas temperature by a maximum of 50°C at 104 standard m^3/min. Final decontamination of off-gas particulates is achieved in the two-stage HEPA filter

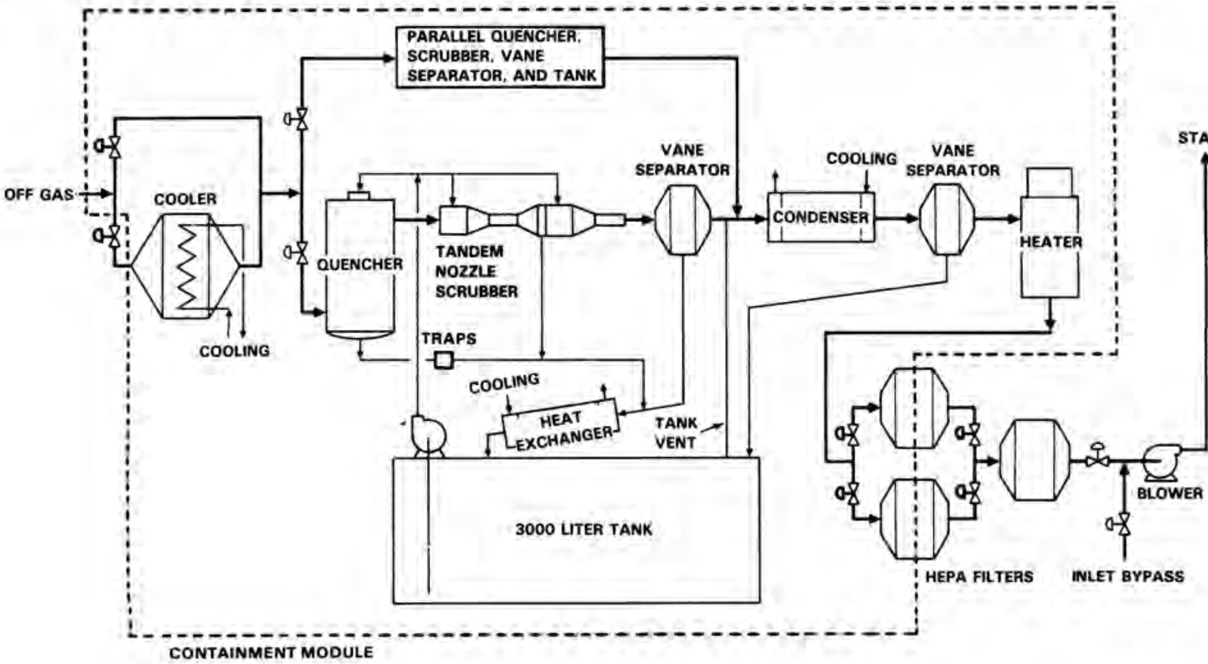

Fig. 4. Off-gas system for large-scale in situ vitrification.

assemblies. The first stage is composed of two parallel housings, each capable of holding four 61-cm x 61-cm x 30-cm deep filters. If a filter's differential pressure becomes too high, the off gas will be automatically diverted to the parallel housing.

The gaseous effluents are drawn through the off-gas system components by an induced draft system. The driving force is provided by a 149-kW (200-hp) blower capable of achieving 104 standard m^3/min at 90°C and -229 cm of water. A backup blower rated at one-quarter the capacity is also provided in the event of failure of the primary blower. The backup blower is not intended to provide excess combustion air, but rather to maintain a negative pressure on the off-gas hood to prevent direct release of effluents until the process can be safely shut down. The backup blower is automatically activated by the process control system when the header vacuum is reduced below a preset limit. After the blower system, the off gases are exhausted to the stack, which is monitored continuously for radionuclides, NO_x, and SO_2. The stack is removable and extends high enough to prevent interference with the off-gas and control trailer's heating, ventilating and air conditioning (HVAC) systems.

Glycol and Cooling System

Glycol cooling solution is pumped between the support trailer and off-gas trailer to remove the heat from the gaseous effluents. The glycol is recirculated between trailers through flexible jumpers by two pumps in two independent loops. The glycol recirculating through the heat exchangers and condensers is kept separate from the glycol loop for the gas cooler. Both loops, however, are assembled in one glycol cooling assembly which is located on the support trailer. The assembly consists of two fan-cooled radiator systems, each dedicated to its respective glycol loop. The entire assembly will remove 1600 kW at an ambient temperature of 38°C.

Process Control Station

The process control station consists of a distributed microprocessor monitoring and control system, and a control console for the power supply. The process control station monitors and controls important process parameters. In addition, it automatically activates backup equipment or reroutes off-gas flow in the event that certain equipment fails.

The distributed microprocessor control system consists of three process control units and two operator interface units. The process control units are connected to critical and informational sensors located throughout the process. These include sensor readings from pressure elements, thermocouples, gas monitors, and flowmeters. In addition to monitoring key parameters, the control system controls the pressure drop across the scrubber systems by pneumatic flow control valve at the blower inlet. The system also controls the blower inlet vacuum with a separate pneumatic valve that governs the magnitude of recycle through the main blower. The system can automatically activate the standby scrubber system if hood vacuum or oxygen concentration were to be reduced. The control system also provides automatic batch logic sequencing of specific operations in the event of equipment failure. For example, in the event of power failure, the control system will automatically restart the off-gas system in a preprogrammed sequence. If pressure drop exceeds predetermined levels, the system will automatically activate the parallel HEPA filter assembly. And if the primary blower fails, the system will automatically shut down power to the electrodes and start the backup blower.

Although the control system is connected to sensors and to an automatic shutdown circuit on the electrode power supply system, it does not directly control the power supply. A separate control console fulfills that function. The power supply controller provides the necessary saturation current to the saturable reactors that govern the power to the electrodes. This control module maximizes efficiency of the electrode power system and provides a quick reduction in power in the event of off-standard conditions.

Off-Gas Support Equipment

Various support and backup equipment are necessary to ensure the safe operation of the off-gas system. This equipment provides electrical, water, and air services to the off-gas equipment. The support equipment includes a 750-kVA transformer; a motor control center; a 112-kVA transformer; a 750-kVA diesel generator; an air compressor; and a process water supply tank, pump, and agitator.

Other than electrical power, the ISV process is entirely self-contained. No outside water, sewer, or air services are required. Supply and waste waters are transported by tank truck on an as-needed or scheduled basis. The process is equipped with its own air compressor for actuation of the pneumatic valves, and its own water supply tank for scrub solution makeup.

Power to the off-gas process equipment is provided through the 750-kVA transformer and distributed by the motor control center. The 750-kVA transformer provides 480-V power to the motor control center from a 13.8-kV supply. If power is interrupted to the transformer, a transfer switch in the motor control center will automatically activate a standby 750-kVA diesel generator that is equipped with its own battery powered cranking system. This generator will provide emergency power to all off-gas system components including the pumps and fans of the glycol cooling assembly, the two scrub pumps, the heater, the blower system, the air compressor, and monitoring and control instrumentation. The motor control center, located in the control trailer, provides power to this equipment as well as to the power supply control console and the supply pump and agitator for process water. The 112-kVA transformer, which provides 240-V and 120-V power from the 480-V supply, is also located in the control trailer. The 120-V power is also tied into the emergency backup power generator for emergency lighting.

CONCLUSIONS

The large-scale ISV process, which stabilizes contaminated soil in place, is self-contained in a transportable system. The process equipment is mounted in three trailers for easy transport among various waste sites. Other than 13.8-kV electrical power, the large-scale system requires no facility services, such as compressed air or cooling water.

The ISV process is designed and fabricated using commercially available equipment. The avoidance of special design or fabrication results in reduced capital costs and reduced replacement costs for process equipment. To control operational costs, the total system is designed to be operated under normal conditions by two operators per shift. The system's flexible design features make ISV a viable option for remedial action for contaminated soil sites.

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