APPLICATIONS OF POWER FLUIDICS™ TECHNOLOGY IN NUCLEAR WASTE PROCESSING PLANTS

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ABSTRACT

Power Fluidics Technology has been used for the transport, mixing and sampling of nuclear waste in liquid or slurry form in nuclear waste processing plants in the UK for more than 30 years. The key feature of the technology is the absence of mechanical moving parts in contact with the process fluid with the resulting benefits of inherent plant safety, reliability and reduced operator dose uptake due to reduced maintenance requirements. These benefits are accompanied by a reduction in secondary waste generation.

This paper describes the principles on which fluidic pumping, sampling, mixing and ventilation systems are based and uses practical examples to demonstrate how the technology has been applied in the UK and how it is being applied in the US in nuclear waste processing plants.

INTRODUCTION

Power fluidic pumps, samplers, mixers and ventilation control equipment use compressed air and geometric effects to affect liquid and air flow. Pumps and samplers are capable of operating without flow dilution and with significantly reduced susceptibility to erosion or blockage. Power fluidic mixers are capable of mobilizing tank-bottom solids and mixing without the use of rotating equipment or seals. Ventilation control equipment such as Vortex Amplifiers (VXAs) are capable of regulating flow to glove boxes or enclosures in failure or fault situations demonstrating an extremely fast response time without the use of electromagnetic valves which are liable to periodic failure and therefore require maintenance. In addition they contain no oil as in alternate control systems such as those using bubblers which can lead to contamination of air lines.

Initial applications of the technology focused on sludge mixing/pumping and ventilation system control in new-build nuclear processing plants and a number of designs of pumps and mixers were demonstrated as being capable of handling high-viscosity, high-SG materials. Since then, well in excess of 400 pumps, mixers and VXAs have been designed, installed and are operational within UK reprocessing plant and have a combined operational life in excess of 4500 years without catastrophic failure (1). Individual units have operational lives in excess of 20 years, again without failure. In the US, the fabrication of Waste Treatment Plant, being managed by Bechtel National Inc, at the DOE’s Hanford site is incorporating some 400+ Fluidic components into the vitrification facility in liquid, low solid and high solid applications.

Recent adaptations of the technology have resulted in both mobile and fixed systems for the mixing and retrieving of wastes from underground storage tanks across the DOE complex as part of the EM Cleanup effort.

UK Development History

Fluidics was originally developed in the Aerospace industry as an alternate to unreliable and complex mechanical systems. This form of Fluidics is often referred to as 'Signal Fluidics'. With the advances in solid state electronic circuitry, signal fluidics was rapidly overtaken as the preferred technology and largely abandoned.

However, it was recognized that some aspects of the technology could be modified and utilized within the process industries where reliability and reduced maintenance were high priorities. Development programs funded largely by British Nuclear Fuels Ltd (BNFL) in collaboration with AEAT, industrial partners and the Universities of Sheffield and Cardiff advanced the use of fluidic principles in a technology now known as 'Power Fluidics'.

As part of this development, AEAT designed and fabricated a number of pump test facilities that were used to support the development of design simulation software for modeling fluidic pump and mixing systems. This software FLUMP (FLUidic Modeling Program) was validated using water but has the capacity to simulate pump performance over a wide range of liquid physical properties, temperatures and delivery geometries. It has been proven to be a very useful diagnostic and simulation tool and has been applied to a wide range of flow-rates and mixing conditions.

Prior to freezing the design of an active facility, policy was to test at an appropriate scale all applications that were beyond their envelope of knowledge and experience. This enabled many system operational characteristics to be defined on inactive facilities and 'iron out' many design challenges before reaching the active plant. For many years, AEAT supported BNFL with the development and testing of fluidic pumping and mixing systems for these key applications.

Typical examples range from the development of full scale hydraulic models of Highly Active Evaporation and Storage vessels and delivery routes (HALES) to mixing and sampling trials for key vessels within the Thermal Oxide Reprocessing Plant. Key to all this trial work was the choice of simulant and the properties of the real material the simulant would be used to replicate. In some case depleted Uranyl Nitrate would be used to give the liquid properties and would be loaded with solids of the appropriate density and particle size range. In other examples simple aqueous solutions loaded with particles could be used and extensive test programs completed.

Prior to installation at an active facility, it is policy to performance test all fluidic pump and mixer components on purpose built test facilities. This eliminated any concerns with the performance of the components due to materials, manufacturing defects or incorrect specification and eliminates any manufacturing concerns as a source of any performance issues during commissioning.

Of principal interest during the technology development were systems that could safely and reliably transport, mix and sample highly active liquids and slurries as part of reprocessing activities.

The benefits recognized from this development work were:

- No moving parts in contact with the process fluid
- No seals
- No in-cell maintenance
- No heating or dilution of the fluid as observed with steam ejectors
- Reduced dose uptake and downtime due to minimal maintenance requirements

These benefits led to the technology being widely adopted in the UK Nuclear Industry chiefly at the BNFL Sellafield reprocessing facility but also at other UK sites such as Aldermaston and Dounreay.

Principles of Power Fluidic Pumps, Mixers and Sampling Systems

Introduction

Fluidic mixing, pumping (fig 1) and sampling systems use compressed air as the motive force for the movement of the liquid. Each system features a charge vessel (CV) which is a fluid reservoir which is filled or discharged by the evacuation or pressurization of the void space above the liquid level. The control of the air into and out of the Charge Vessel is accomplished using a Jet Pump Pair (JPP), designated the fluidic system Primary Controller. The JPP comprises two back-to-back ejector elements. Its purpose is to:

- Supply a positive gas flow and pressure to the charge vessel during the drive phase
- Provide a vent path for this gas during the vent
- Produce a partial vacuum in the charge vessel during refill

The internal geometry of the device is specially designed to fulfill these roles.

For the pumping system a Reverse Flow Diverter or RFD element is utilized. It consists of a pair of opposed nozzles set into a 'Tee" piece is used to direct fluid from the supply vessel into the CV line aiding refill and thereby achieving transfer to the delivery vessel (fig 1.)

The equipment upstream of the Jet Pump Pair is designated the fluidic system Secondary Controller. Its purpose is to:

- Control the duration of the drive phase and to supply compressed air to the "drive" part of the JPP during this phase
- Control the duration of the vent phase and to switch off the air supply to the JPP during this phase
- Control the duration of the refill phase and supply compressed air to the "suction" part of the JPP

The compressed air on/off control is usually accomplished using conventional actuated valves, which only need to handle clean gas and are installed in an accessible position so that maintenance can be performed. The sequencing of the valves is controlled by AEA Technology's patented PRESCON™ controller which determines when the charge vessel is full and maintains the correct phase times in the operating cycle by analyzing the pressure signals from the compressed air line and is thus totally non-intrusive.

The nozzle of a pulse jet mixer is an engineered opening designed to give a desired flow pattern for the fluid exiting from the charge vessel.

The pulse jet mixer system mobilizes waste via a three phase mixing process:

- Suction phase
- Drive phase
- Vent phase

The pulse jet system remobilizes the sludge contained within the designated supply tank by first sucking liquid out of the tank into the charge vessel, entraining a small amount of sludge. This liquid is then repeatedly forced backwards and forwards between the tank and the charge vessel using compressed air, thereby gradually entraining more sludge into the liquid.

During this operation, gas is vented out of the jet pumps to an off-gas system. The mixing process is repeated until the sludge/liquid mixture around the tank nozzle breaks through into the overlaying supernate layer. Once this occurs, the mixing cycle continues until the required suspended solids composition is reached, at which point the mobilized sludge/liquid is pumped out of the tank. Tank emptying is achieved by filling the charge vessel from the designated supply tank and then discharging the charge vessel via a valve manifold to a delivery line, instead of back into the storage vessel

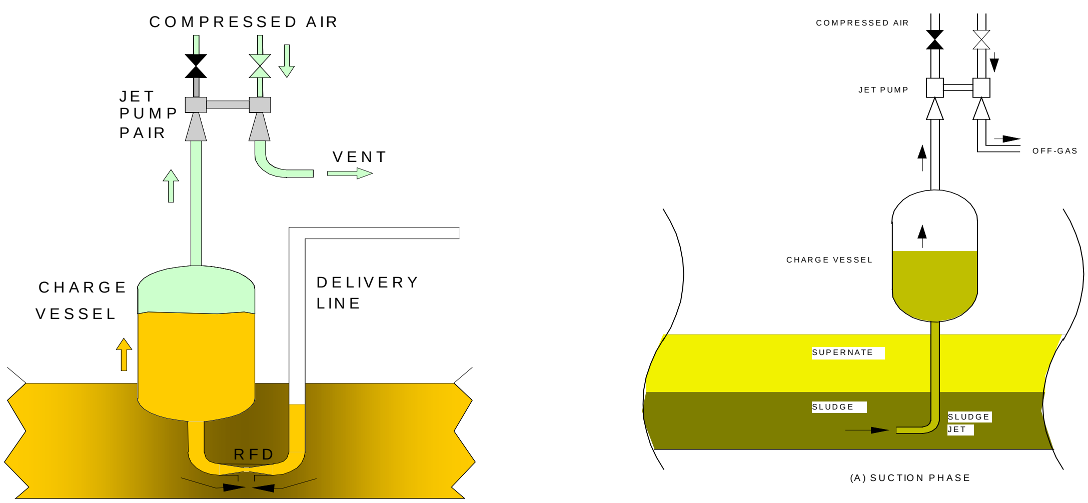


Fig. 1. A simplified fluidic pumping and mixing arrangement

The system configuration may be further modified by the addition of a remotely operated directional nozzle which is incorporated into the system above or below the charge vessel. Liquor is initially sucked from the tank to fill the charge vessel as in the transfer operation. The contents of the charge vessel can be discharged through this nozzle via a valve manifold. During the drive phase, the liquid jet emerging from the nozzle dislodges sludge adhered to the tank walls. The sludge, which then falls to the bottom of the tank, can be maintained in suspension using the mobilization mode of operation described

Principles of Power Fluidic Ventilation Control Systems

Introduction

The Vortex Amplifier (VXA) is a variable resistance valve with no moving parts. When applied to the control of glove-box extract ventilation the major benefit of the VXA is it responds almost instantaneously to changes in conditions, has no moving parts and requires no maintenance. They are therefore more reliable and faster-acting than traditional mechanical systems.

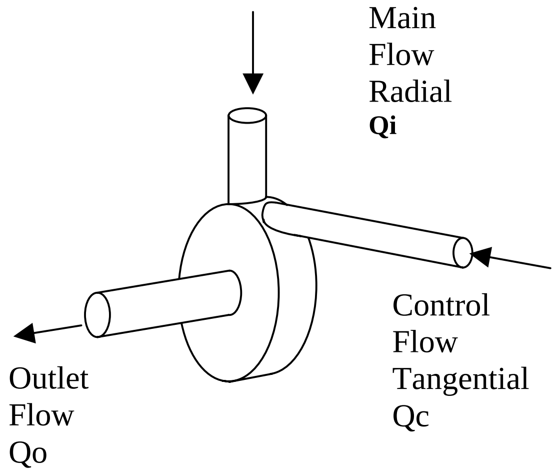
Since the VXA has no moving mechanical parts it can be readily manufactured from a very wide range of materials to ensure compatibility with particular plant conditions. For UK nuclear applications the units have generally been made in stainless steel.

Description

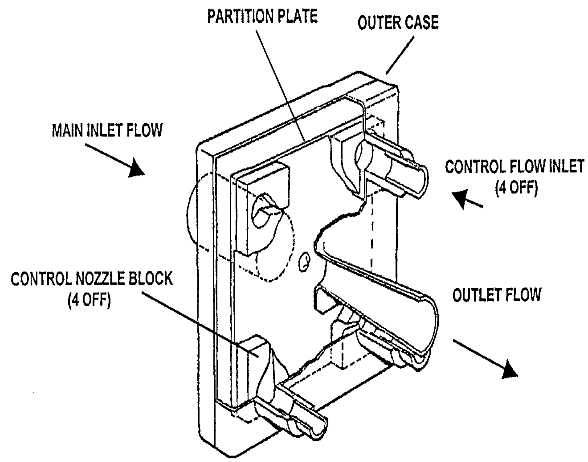
A Vortex Amplifier consists of a short cylindrical chamber with an axial outlet, a radial main inlet, and a tangential control flow inlet. When flow is entering through both the radial and tangential inlets a vortex forms inside the chamber, creating a significantly larger pressure drop across the device than would be the case if the flow into the chamber were entirely radial. The relative strength of the vortex depends on the ratio between the tangential control flow Qc and the radial main inlet flow Qi, and hence on the relative pressure differentials across the control inlet port and the main inlet port.

This simple configuration of the Vortex Amplifier is not entirely convenient from the point of view of plant installation. The practical embodiment of the basic device is often formed as a square box with a conical outlet connection on the center. An internal square "partition plate" is supported from the downstream side of the box, spaced from it by four "control nozzle blocks". The vortex chamber is now the space between the partition plate and the downstream side of the box.

The single radial main inlet port of the simple Vortex Amplifier configuration is now replaced by the four radial gaps between adjacent control port blocks, and each of the blocks has a tangential control flow inlet port formed in it. The control flow enters the device through four pipe connections perpendicular to the downstream face of the box, and the main inlet flow enters the device through a connection on the upstream face of the device, passes round the partition plate, and enters the vortex chamber through the radial gaps between the control port blocks.



Simplified Vortex Amplifier



Practical Vortex Amplifier

Fig. 2. A vortex amplifier

Successful Applications of Power Fluidics Technology in the UK

Power fluidic pumps and mixing systems have been utilized in the UK reprocessing industry for in excess of 30 years. Some 291 RFD pumps and 141 pulse jet mixers are installed in vessels at the BNFL Sellafield Reprocessing facility and have combined operational lives in excess of 4500 years with no record of irrecoverable decline in performance.

Typical applications of the RFD pump in the Sellafield Reprocessing plant are as follows:

Thermal Oxide Reprocessing Plant – THORP	200+
Encapsulation plants e.g. EP2	23
Enhanced Actinides Recovery plant - EARP	4
Vitrification plants - WVP	20+
Highly Active Storage Tanks – HAST	6
Solvent treatment plant STP	25
Waste Packaging and Encapsulation Plant	20

The HAST tanks are used to store highly active fission products solutions after reprocessing and the RFD pumps were installed with redundancy as emergency backup due to their reliability, mechanical simplicity and ability to pump solutions close to boiling in the event of cooling problems.

A white paper written in 1992 (2) says that pumps in active service in both HAST and WVP "are performing satisfactorily, being trouble and maintenance free even though they are used for slurry (up to 16%w/w) transfer". This is further reinforced by another study paper (3) that states "RFD pumps have proved to be particularly suited to handling all types of slurry ranging from sludges and flocs to metallic debris" thereby demonstrating the real-life flexibility and functionality of this family of process plant.

Successful Applications of Power Fluidics Technology in the USA

Introduction

AEA Technology with the support of the US DOE Office of Science and Technology and the US DOE sites at Oak Ridge TN, Idaho Falls ID, Los Alamos NM, Mound OH and Richland WA has been instrumental in transferring technologies and experience from its UK operations to the US nuclear site remediation program (4).

Based upon the Power Fluidic systems and technologies demonstrated for many years in the UK, a number of tank mixing and retrieval systems have been developed, fabricated and deployed. Additionally mobile systems have been successfully operated at sites throughout the DOE complex.

Application 1: Bethel Valley Evaporator Storage Tanks, Oak Ridge, Tennessee

Bethel Valley Evaporator Storage Tanks (BVEST) at the Oak Ridge Site contained sludge generated from the production of nuclear weapons. The sludge made the tanks inoperable and had to be homogenized and transferred to holding tanks, in order to return the BVEST to service. Removal of the sludge was also mandated by the DOE as part of the Transuranic Waste Disposal Program. AEA Technology designed, fabricated, installed and operated a Power Fluidic mixing system to mobilize the sludge and enable transfer.

Within the BVEST complex there are three W-tanks, which contained more than 33,000 gallons of sludge. The tanks measure approximately 12ft. in diameter and 62ft. in length, and have limited access with only one 19-inch manhole. Due to restricted access and internal obstructions within the tank, as well as cost and time constraints, various conventional methods of sludge homogenization were impractical

Making use of the existing sludge jets in the tanks, AEA Technology designed a Power Fluidic system that was able to connect to all three tanks through the existing Pump and Valve Vault (PVV). The system was able to mix sludge with existing supernate in the tanks to produce a homogeneous mixture, which was suitable for transfer. This approach also enabled the transfer of supernate between the tanks thereby minimizing the amount of additional liquid (and therefore secondary waste) needed to homogenize all of the sludge.

To minimize worker exposure, AEA Technology constructed a plywood mock-up of the PVV, which was used for training and dry-run purposes. Use of this mock-up reduced the total worker dose from the ALARA estimate of 4000 mR to only 1230 mR.

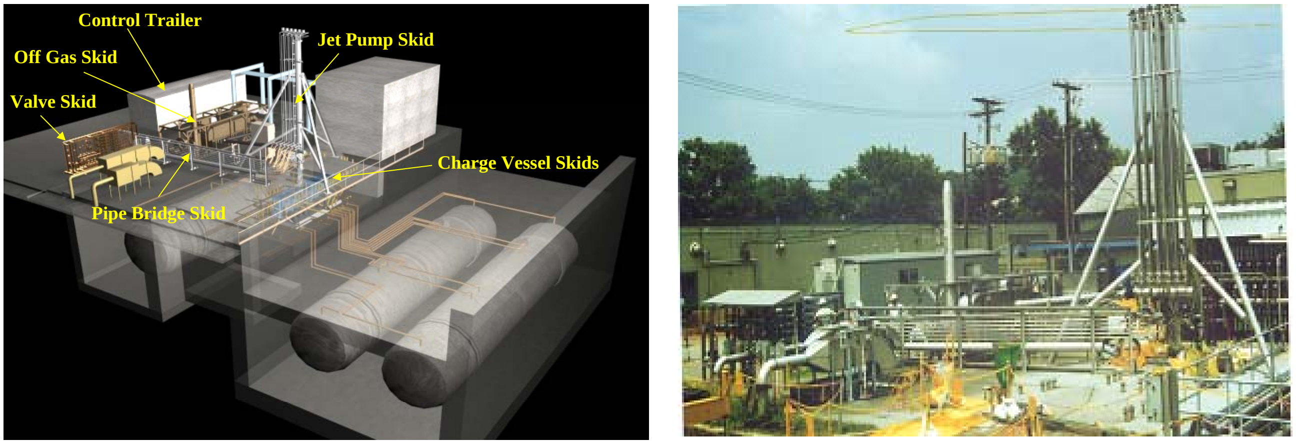


Fig. 3. BVEST tank system CAD drawing layout and final system

Overall, the system homogenized more than 33,000 gallons of sludge (over 98% of the total) with 93% recycle of supernate and the project was completed at a fraction of the DOE baseline schedule and cost.

Application 2: Mound WD Complex, Ohio USA

Designed and constructed in 1948, building WD at Mound was the treatment facility for low specific activity (LSA) radioactive wastes generated by process activities. Active and inactive processes housed within the WD facility included alpha and beta wastewater treatment, laboratory and bench-scale research, LSA waste drum repackaging, a glass melter furnace and a packed bed reactor. One of the challenges the site is facing with deactivating and decommissioning the facilities is waste retrieval and eventual treatment of waste from the 36 waste tanks and sumps in the WD complex containing various types of wastes and varying in size from 1,000-40,000 gallons.

In compliance with the D&D plan for the facility, the contents from the WD tanks will be retrieved and stored until a treatment process is identified. The walls of the tanks will then be washed and the subsequent contents will be retrieved and transported for treatment. Finally, the site will remove the tanks as part of the Facility Decommissioning Project.

Through a contract with the US DOE Office of Science and Technology, AEA Technology was assigned the task of deploying a mobile, skid-mounted tank waste retrieval system to Mound to retrieve the waste from two of the WD complex storage tanks. The system, a Small Tank Mixer (STM), had been previously deployed at Oak Ridge and was then transferred to Mound.

When the initial phase of the waste retrieval was completed in 2001, it was determined that the directional nozzle was very successful in removing the bulk waste from the tanks, but was not effective in removing the crusted carbon sludge from the sidewalls of the tanks.

Therefore, in 2002 AEA Technology modified the system to include the capability to wash the inside of the tanks after the waste was retrieved. A remote controlled articulating nozzle was designed to rotate 360º and travel up and down, vertically, in the tank.

The modified system was able to remove the crust from the tank walls and provided the site with a single system to retrieve the waste and also clean the inside of the tanks, in compliance with D&D milestones.

Application 3: Tech Area 50 (TA-50) Sludge Tank, Los Alamos National Laboratory, New Mexico, USA

The US Department of Energy has a large inventory of storage tanks with unique geometries that contain radioactively contaminated wastes. The TA-50 facility at LANL has a number of such tanks. The properties, quantities and disposition of the waste are unknown; however, it is believed that these tanks contain residual waste that may also be encrusted onto the walls, and could contain solid debris. The presence of this waste is an impediment to safe and efficient site operations and a method was required to mobilize, mix and retrieve the waste from these tanks.

During 2001, AEA Technology completed design and functional testing of a directional nozzle system suitable for mobilizing and recovering sludge from the TA-50 facility Sludge and Influent Process Tanks prior to their return to service. During 2002, AEA Technology supplied a skid-mounted tank waste mobilization and retrieval system to the TA-50 facility at LANL to start mobilizing and retrieving the legacy waste from the tanks at this facility. Active operations commenced in October 2003.

Mobile Fluidic System Benefits

In summary, the mobile fluidic tank waste retrieval system provides the following benefits:

- Proven technology with a record of accomplishment in safe, successful and efficient operation in the field.
- Promotes and maintains ALARA principles for worker radiological exposure.
- Site operators can be quickly and comprehensively trained to operate the equipment.
- Mobile, modular equipment easily deployed and readily relocated for use on further tank waste retrieval applications.
- The system can mix tank contents to obtain a homogeneous sample of the tank contents and establish confidence regarding the nature of the waste form and tank contents to assist in regulatory compliance.

- Systems can be remotely operated a safe distance away from the radiological/hazardous area, resulting in low to negligible radiological exposure for workers.
- System geometry and modular construction allows the system to be easily decontaminated for ease of transportation and storage
- Robust principle of operation reduces the risk of operational disruption due to unexpected waste forms or foreign objects in the tank.
- Assemblies installed in the tank can be supported by bridging structures, eliminating unacceptable loading on aging or degraded structures.
- Retrieval skids can be located a safe distance away from the tank to reduce tank-top loading.
- Secondary waste generation is reduced by minimizing the amount of water required to recover sludge in tanks.

Recent Work at the WTP (Waste Treatment Plant) at Hanford

Introduction

The baseline design of the WTP project as prepared by the original prime contractor, BNFL, makes extensive use of Power Fluidics within the facility particularly in areas where maintenance would be non-contact and difficult to perform. In black cell areas, fluidic pumps were chosen because of their demonstrated reliability, and reduced maintenance requirements.

The Project

An AEAT led team of engineers calling on skills from both AEAT and BNFL were contracted to support the project in two ways:

- By designing, manufacturing and performance testing some 400 components of the pumping and mixing systems such as those shown below in fig4.
- By providing support to the Research and Testing Program and Computational Fluidic Dynamics program for the analysis and solution to numerous mixing challenges.

Jet Pump Pair

RFD Units

Fig. 4. Typical production Power Fluidic components

In total approximately 80 RFD pumps are being used in both transfer and sampling applications. Whereas approximately 30 tanks contain some form of fluidic agitation system.

To support these activities, AEA Technology set up a local office in the Richland area and staffed it with suitably qualified and experienced staff from AEA Technology and BNFL within the US and from the UK. In parallel, a series of US fabricators were identified and down selected for the manufacturing process on the basis of manufacturing capability, capacity and appropriate quality standards. The 400+ components were designed, fabricated and delivered in accordance with the agreed schedule and AEA Technology is continuing to support the project through a Technical Services Agreement.

SUMMARY

In summary, AEA Technology's Power Fluidics technology has been demonstrated to have a number of benefits in both process plant and for waste retrieval and mixing operations in both the UK and the USA. The technology has a long history of success and can be delivered to US and UK programs through AEA Technology and its existing and proven network of fabricators.

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