Using a Full Scale Support Rig to Enhance the Performance of the Waste Vitrification Plant at Sellafield - 14590

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ABSTRACT

The Waste Vitrification Plant (WVP) converts Highly Active Liquor (HAL) from spent nuclear fuel reprocessing into a stable vitrified product. During the first decade of operation, WVP failed to operate at basis of design throughputs and waste incorporation rates. As a consequence, WVP came under pressure from the UK regulator to progressively reduce holdings of HAL waste stored in above ground tanks. To enhance performance, a decision was taken to invest in a full scale Vitrification Test Rig (VTR) to support WVP.

The mission of the VTR was to increase waste throughput in terms of processing rates and the amount of waste incorporated into the glass product. During the first two years of operation the VTR was able to demonstrate these objectives by raising throughput from 21 kg/h to 28 kg/h and incorporation from 25 %w/w to 28 %w/w to underpin WVP plant performance.

The advantages of having a full scale support facility were clearly demonstrated in the initial two years of operation, leading to a significant extension of the work programme for the VTR. Experimental work carried out on the VTR led to further advancements in throughput and incorporation and a significant broadening of the operational envelope for WVP to help extend equipment life, optimise process conditions and demonstrate the glass product quality. Further benefits have been; training of operational and support staff for WVP, improved operability of WVP and a platform for rehearsing recovery of breakdowns and mal-operations. The VTR is currently being used to support the vitrification of post operation clean out wastes as WVP approaches the end of its scheduled life cycle.

The benefits of the VTR being full scale can be clearly demonstrated by removing any arguments with respect to “scale-up” issues. Products generated on the VTR and the conditions under which products are manufactured are directly comparable to those on WVP.

INTRODUCTION

The aim of this paper is to describe the benefits and learning of concurrently operating a full scale, non-radioactive test rig in support of WVP based at Sellafield. The VTR when built in the early 2000’s represented a significant financial investment for the incumbent site operator. The decision driving this investment was governed by increasing pressure from the UK regulator to progressively reduce the volume of Highly Active Liquor (HAL) held in above ground storage tanks against a background in which WVP was not operating at design throughputs. Even though a third production line was being commissioned, Sellafield management made the decision to build a full scale test rig to carry out underpinning development work to improve the rate at which HAL was converted into vitrified product.

WVP manufactures a vitrified product from HAL in a two-stage calcination and glass making process. The product conforms to a specification and the quality is guaranteed by manufacturing the product within a pre-defined operating envelope. WVP does not have a routine capability to sample its product; therefore any changes to its operating parameters need to be underpinned off-line on a suitable test rig. The proposed operational changes are reproduced on the test rig and the resultant product quality is qualified by sampling and analysis. Having proven that the product quality is acceptable, the revised operating envelop is applied on WVP.

In order to meet the above requirements the VTR was designed, constructed, commissioned and handed over to operations between 2000 and 2004. A major decision point in the design of the VTR was the scale of the test rig. Experience of supporting WVP with a previous test rig, which was not to the same scale as WVP, had highlighted issues in applying the data produced at pilot scale to the full scale plant. Not having an identical scale test rig led to issues such as convincing stakeholders and customers of technical arguments where some degree of extrapolation or interpretation was required. Having considered such issues the decision to go “full scale” using identical equipment was made. The additional financial investment required was considered worthwhile given the potential shortfalls associated with the extrapolation of data.

VTR CAPABILITY

Process:

A flow diagram of the VTR is shown in Figure 1. Simulated HAL (metal nitrates in nitric acid) is mixed with sucrose solution (reducing agent) and fed into a rotary tube calciner furnace. The calciner tube is angled at a shallow downward slope to allow the HAL to flow under gravity. The liquid components within the HAL are evaporated in the upper end of the tube furnace and the resulting solid metal nitrates are largely de-nitrated and converted to metal oxides in the lower end. The resultant calcine product then exits the tube at the lower end via a series of slots in the tube. The calcine drops by gravity into an induction heated melter crucible. Borosilicate base glass frit is simultaneously batch fed into the crucible, and the two components are mixed with an air sparge arrangement to aid reaction. Typically it takes between 7 and 8 hours to charge the melter crucible. Once a charge period has been completed, the glass is held within the melter until the average temperature of the melt, as measured by several internal thermocouples, reaches a predefined value (typically 1050^{o}C) and is then poured into a storage container. When cooled, the product container can be opened allowing the product to be exposed for initial observation and examination. The product can then be broken down for sampling and subsequent analysis.

The primary off gas system (POG) abates any volatile elements or fine calcine particles that are suspended in the off-gas flow and the gaseous products of the calcination process (primarily water, nitric acid vapours and NO_x gases). The key components within the POG are; a dust scrubber to remove solid particles, a condenser to remove water and nitric acid vapours and a NO_x absorber to remove any remaining NO_x gases. Solids abated in the dust scrubber are dissolved in nitric acid and the resultant scrub solution is recycled back to the calciner.

Condensed nitric acid and water are collected in the condenser forming a liquid effluent. NO_x is abated in the NO_x absorber producing a weakly acidic effluent. These effluents are sentenced to dedicated effluent storage tanks prior to disposal. All of the vessels that make up the POG can be sampled and the liquors analysed. The process is kept at a constant depression in order to contain all of the process off gas within the plant and prevent the release of NO_x (and, on WVP, radionuclides) to the cell.

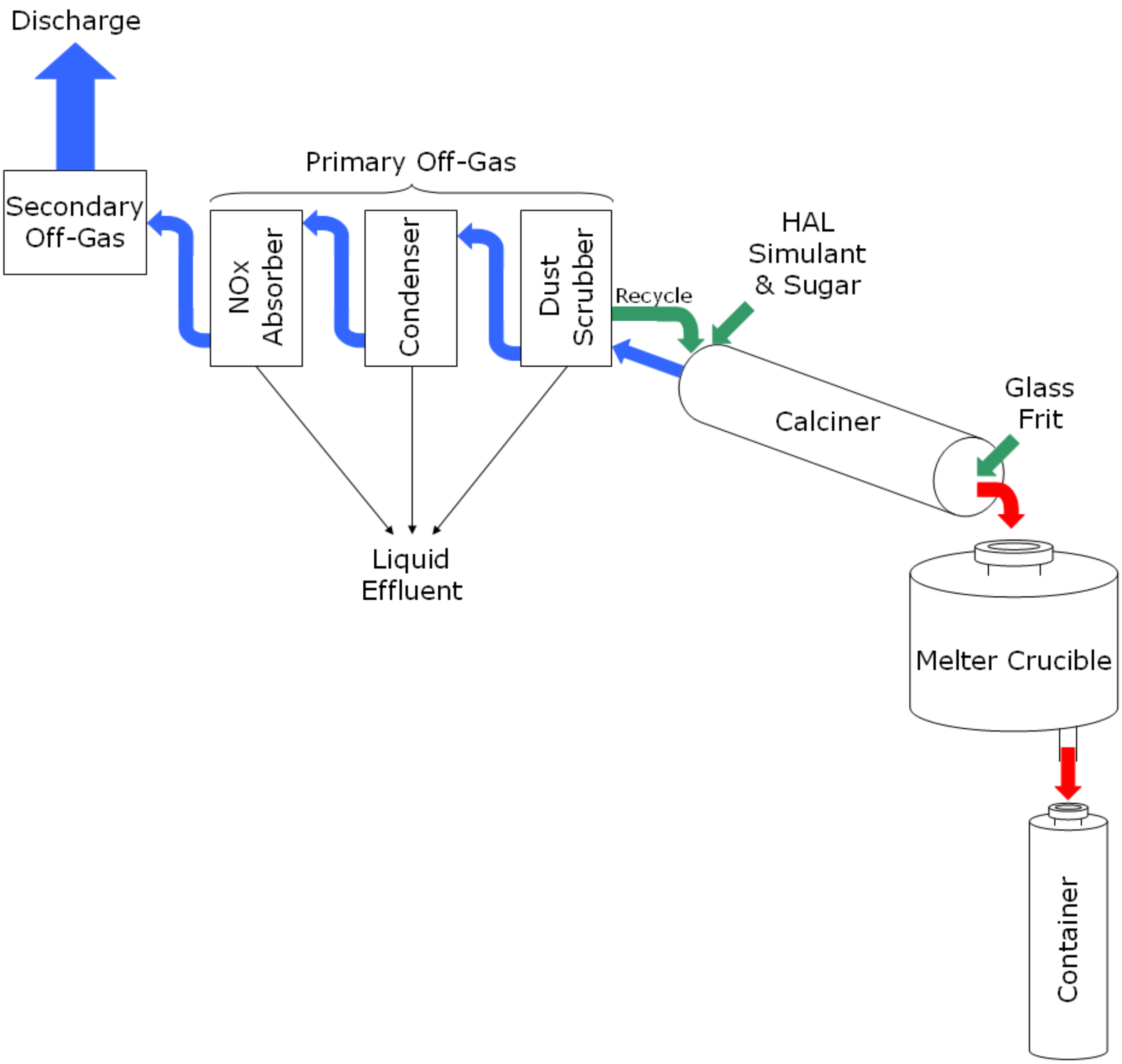

Fig. 1. Schematic of the VTR

Since the VTR is a test rig, it is furnished with a broader array of instrumentation than that fitted to the WVP production plant. Furthermore the VTR was fitted with a control system very similar to WVP. This included a process explorer software package which proved valuable in interpreting production data. The advantages of having a control system very similar to WVP is that it facilitated the ability to rapidly interchange operational personnel between the VTR and

WVP and vice versa. A further consideration in the design of the VTR was chemo-toxic safety. Unlike WVP where high levels of radiation exclude operators from close proximity with the process equipment, the VTR facilitates such close access. Therefore the facility was designed with several additional key safety features to protect operators when working in close association with chemo-toxic hazards

A conscious decision was made during recruitment of the operations team to employ scientists and engineers. This ensured that the focus of VTR operations was clearly around understanding the underlying science and technology and not just around delivering production. Furthermore the operators were carefully chosen to have a questioning attitude and an approach that focused upon understanding the unusual.

The vitrification process is a continuous process and therefore the VTR is operated on a 24/7 basis. Experimental programmes are delivered in operational campaigns of 4 to 8 week duration. In the period 2004 to 2008, three to four such campaigns were completed each year. In subsequent years, once the main throughput objectives had been delivered, the VTR was operated less intensively. However the facility has been retained by WVP as it provides considerable operational risk mitigation and facilitates the development of new process flow-sheets to meet changes in reprocessing schedules and to cope with wastes arising from decommissioning of the Highly Level Waste Plants (HLWP).

BENEFITS

The majority of the throughput improvement benefits were delivered within the first two years of operation of the VTR. An incremental approach to improvement in waste incorporation and processing rates was adopted (slow and steady) giving WVP the chance to progressively implement improvements and reap reward on investment. VTR personnel supported WVP production teams in applying these improvements onto the operational plant. The progressive improvements in both production rate and waste incorporation rate enabled WVP to maximise the processing of HAL. The net impact of this performance improvement was that more waste is added to each product container. The ultimate disposal route for Highly Level Waste is underground geological disposal, the cost per container housed within geological disposal is estimated to be of the order of £ several hundred thousand sterling, and therefore savings made by manufacturing fewer containers was very significant. Furthermore the above improvements mean that containers are produced more quickly which will reduce the overall running time of WVP and therefore lead to a saving in the cost of operating the plant. Such savings were sufficient to recoup both the capital cost of the VTR facility and its operational costs.

The VTR was used to determine the sensitivity of the product quality to certain key process parameters which have specific tolerances which in turn contribute to quality control of the product. Test work on the VTR concluded that the product quality had a wide tolerance to these key parameters. This work enabled a significant broadening of the process envelope which led directly to a situation where a product quality conformance is much easier to achieve. Avoiding non-conformance represents a further tangible cost saving as a value can be assigned to each container which can be returned to the customer or provides underpinning for suitability for UK disposal.

Operation of the VTR by dedicated science and engineering teams has resulted in a better technical understanding of the process. Not having the direct pressure of meeting production targets allowed the VTR team to learn how to operate the VTR efficiently; this led directly to improvements which could be transferred to the production plant. Some key examples are; improved melter control which assists in extending melter life times, fine tuning of calcination additive rates to optimise the dust burden of the off gas system and management of the calciner conditions to limit deformation of the rabble bar within the calciner which prevents excessive dust formation. Furthermore, operation and experimentation on the VTR led to the development of an independent body of experts who could advise WVP on production issues and provide informed technical support.

Since the VTR is largely a direct copy of WVP, it has proven very useful as a facility on which WVP operators can be trained and gain experience. The commonality of the control systems on WVP and VTR also facilitates this process. WVP frequently transfers operational and technical staff onto the VTR as part of a skills development programme. The fact that the VTR is non-nuclear enables WVP personnel to gain a unique opportunity to get close-up and hands-on to equipment that would otherwise only be visible from outside a highly active cell environment. The VTR provides a source of trained, skilled personnel which can be deployed on the operational plant. This latter capability was utilised extensively during the early period of VTR operation.

Work carried out on the VTR has assisted WVP in understanding and coping with mal-operation scenarios. The VTR has been used to demonstrate recovery procedures and continuity of satisfactory product quality for a range of plant mal-operation conditions. The benefit of such work is that WVP could continue operations to the next scheduled outage rather than go into an enforced shut down. Some examples being; continued operation without key melter thermocouples, continued operation without a pre-heater furnace and continued operation with failed calciner heating elements.

The VTR presents WVP with a unique opportunity to rapidly troubleshoot production problems as they arise. Having a like for like facility enables the VTR team to investigate and resolve problems with a high degree of certainty that the solution will work when transferred to the active plant. An example of this was deployment and testing of external heating equipment to minimise and control blockages forming in the primary off gas system.
Similarly the VTR enables WVP production teams to rehearse recovery and maintenance procedures. A recent example of support in this area was the calibration of several replacement constant volume feeders before they were deployed into the active plant.

The VTR represents a capability which enables a high degree of flexibility to adapt to change. For reasons stated above, the test facility enabled responsiveness to changes in the process which occurred during the life cycle of WVP. Work carried out using the VTR led to operating procedures being developed to treat more dilute feed stocks, changes to feed compositions resulting from changes in reprocessing schedules and feed material which will arise when the HLWPs are decommissioned.

On occasions during the operational life of the VTR, the test facility has been used as a source of emergency spares for the active plants. Since much of the VTR equipment is identical to WVP, many of the plant equipment items can be used as spares. This has happened on occasions. The VTR is also used to identify obsolete consumable parts of the plant and to source suitable replacement components prior to WVP encountering the same issues.

CONCLUSION

The discussion above highlights many benefits from operating a full scale, non-nuclear development facility to support an operational nuclear production plant. Some benefits are easily measured in terms of cost savings; such as more waste per container, more containers per year, reduced operating life of the plant, and ensuring products are within specification. Other benefits are less tangible e.g. training operations teams and trialing recovery procedures but such capability has a real value. The fact that WVP has supported and is continuing to support a full scale facility is testament to its value despite the significant revenue required to build and operate it.

The experience of the VTR can be applied to other nuclear production plants. However to the best knowledge of the author, the VTR is the only full scale support facility currently operated in support of Sellafield Ltd plants, although learning from the VTR experience may well be applied to new plants which are currently being designed.

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