

## **Oil Immobilization Program at Sellafield: An Innovative Approach**

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### **ABSTRACT**

Non-standard and hazardous wastes pose significant challenges to waste management organizations, particularly given that suitable treatment and disposal routes do not exist for some wastes and those that do are often not cost-effective. Radiological and other chemical contamination increases the challenges posed by the disposal of such wastestreams [1]. Waste oil is one such non-standard wastestream that has proved difficult to manage in terms of treatment and disposal on the Sellafield site.

Nochar polymer technology has been successfully deployed in the immobilization of waste oil by a number of non-UK nuclear facilities [2]. The identification of this technology by British Nuclear Group led to initial discussions between Waste Characterisation & Clearance (Waste C&C) and Pacific Nuclear Solutions Inc., the distributors of the product, in late 2005. Compatibility testing of oil wastestreams held by Waste C&C at Sellafield with the Nochar absorbent polymer systems commenced in January 2006 and three experimental campaigns have been undertaken during 2006. The objective of this small-scale test program was to test the ability of the polymer systems to immobilize a range of aged, chemically- and physically-diverse, radiologically contaminated oil wastestreams held at Sellafield.

### **INTRODUCTION**

British Nuclear Group is a specialist site management and nuclear clean-up business, which manages fourteen operational sites within the United Kingdom, including one of the world's most complex nuclear sites at Sellafield, Cumbria. One of British Nuclear Group's key strategic intents is the delivery of accelerated safe, secure and cost-effective nuclear clean-up. On the Sellafield site, nuclear clean-up is particularly complex given the range of processes and wastes that exist on the site. The Sellafield site holds a variety of wastes – HLW, ILW, LLW and non-standard/hazardous wastes – that pose unique challenges in terms of treatment and disposal.

Waste oil is a non-standard wastestream that has proved difficult to manage in terms of treatment and disposal on the Sellafield site. There is a significant volume of used oils of various specifications which have, in the historical absence of a treatment and disposal route, accumulated on the Sellafield site.

The challenge of waste oil treatment and disposal at Sellafield is exacerbated by a number of factors. The historical absence of a treatment and disposal route (with the exception of very limited scale incineration) and varying waste storage arrangements have contributed to the development of a stockpile of legacy waste on the Sellafield site which is aged, in some cases degraded, and both radiologically and chemically contaminated. This legacy waste oil poses a significant risk to both people and the environment, given its chemo- and eco-toxicity. As such, the Waste Characterisation and Clearance division of British Nuclear Group, Sellafield have been seeking technologies for the treatment and disposal of waste oil. It is the strategic intent of the group to utilise incineration technology for the bulk disposal of waste oil, as this is considered to be the most cost-effective and environmentally sound methodology for bulk disposal. However, it has been identified that some oil wastestreams will fall outside the waste acceptance criteria for incineration, and thus alternative waste routes are required to treat and dispose of this material.

Nochar polymer technology has been successfully deployed in the immobilization of waste oil by a number of non-UK nuclear facilities [2]. This technology was considered by British Nuclear Group as a potential innovative option to waste oil treatment and disposal, as it facilitates the conversion of a liquid wastestream into a solid polymer matrix which potentially opens new disposal routes such as burial at the Low Level Waste Repository (LLWR) at Drigg, Cumbria. This technology offers a solution that reduces the reliance on incineration technology and that offers an alternative disposal routing for waste oil that is incompatible with incineration technology.

The Nochar polymer technology has been demonstrated to immobilize a range of highly complex oil, organic, aqueous, acidic and basic wastestreams in numerous applications globally [3,4,5,6]. This polymer technology consists of a range of granulated polymer products which act to immobilise a variety of liquid wastestreams via absorption and an inter-molecular bonding process. This mechanism of immobilization is not encapsulation; rather the process converts the liquid material into a solid material via this process of inter-molecular bonding [2]. This material has been shown to be able to immobilize liquid wastestreams with a volumetric increase of typically 5% of that of the liquid wastestream. The solidification process does not create an endothermic or exothermic heat reaction during solidification, no harmful chemical reaction, with little/no airborne particles and so is simple and safe to apply. These products possess characteristics – being non-toxic, non-hazardous, non-biodegradable, produce no leaching of material, maintain long-term stability without degradation and incinerable – which make them attractive for use in industry [2,3,4].

The test program described in this paper is the culmination of three experimental campaigns undertaken at Sellafield during 2006, in association with Pacific Nuclear Solutions Inc. These campaigns involved bench-scale testing of the compatibility of the polymer systems with the oil wastestreams held on the Sellafield site.

## **EXPERIMENTAL CONDITIONS**

The experimental program has been conducted in three phases during 2006. A total of 90 oil wastestreams have been tested in this experimental campaign, including mineral oils, hydraulic oils, mineral/hydraulic mixes and oil/glycol mixes. These wastestreams used in the experimental program were chemically and physically diverse, varying in oil type, age, viscosity, purity and water content.

The polymers used in the experimental program were Nochar N910 Petrobond<sup>®</sup>, N960 Acidbond<sup>®</sup> and N935 Ol-Bond<sup>®</sup>. The N910 polymer is suitable for the immobilization of hydrocarbon wastestreams. N960 can be used for the immobilization of acid, alkali and aqueous wastestreams, whilst the N935 polymer system is suitable for the immobilization of alcohol based and water based wastestreams. These polymer systems can be blended in the event that a mixed hydrocarbon/aqueous wastestream is encountered.

## **EXPERIMENTAL METHODOLOGY**

Bench-scale experiments were undertaken on a range of oil samples using a 1.5:1 ratio (w/w) of oil to Nochar N910 polymer. Oil was poured onto the surface of the polymer bed at a slow, steady rate and allowed to absorb. Light manual mixing of the oil into the polymer bed was then applied if 'pooling' of the liquid on the surface of the polymer bed was observed ('pooling' being an effect where there is immediate solidification at the surface of the polymer bed, thus creating a "skin" that does not permit liquid to be gravity fed into the bulk polymer bed). The material was then allowed to cure for a period of 24-48 hours at room temperature before undergoing simple compression testing to assess the degree of liquid immobilization. Qualitative observations were made and recorded throughout the duration of the experiments.

Any material indicating leaching of liquid upon manual compression underwent additional immobilization testing, using the methodology outlined for the N910 polymer system above, using 1.5:1 oil to N910 ratio with up to 5% (w/w) N960.

A set of five oil wastestreams underwent additional testing, using the methodology previously outlined, to test the ratios required for complete liquid immobilization. These ten wastestreams underwent testing at 2:1, 3:1, 5:1 and 10:1 oil to N910 ratios.

## **EXPERIMENTAL RESULTS**

This section reports consolidated experimental results for a random sample of ten of the wastestreams tested during this experimental campaign.

- Table I describes the Nochar N910 solidification of these ten oil wastestreams, with testing at a 1.5:1 oil/polymer ratio (w/w).
- Table II describes the Nochar N910 and N960 solidification of three of these ten oil wastestreams, with testing at a 1.5:1 oil/N910 ratio (w/w) with 2% (w/w) and 5% (w/w) N960.
- Table III describes the Nochar N910 solidification of five oil wastestreams, with testing at a 2:1, 3:1, 5:1 and 10:1 oil/polymer ratios (w/w).

**Table I – Solidification of oil wastestreams with N910 polymer at 1.5:1 oil/polymer ratio (w/w)**

<b>Sample ID no.</b>	<b>Mass of oil (g)</b>	<b>Mass of Nochar N910 (g)</b>	<b>Observations on absorption</b>	<b>Observations post absorption (after 24 hours curing)</b>	<b>Observations on compression (after 24 hours curing)</b>
I018-A	30	20	Dark brown coloured oil. Pooling of liquid on surface. Mixing required.	Dry, clumpy brown coloured material. Excess N910 visible.	No liquid released on compression. Staining (dirt) visible on filter paper.
I024-A	30	20	Brown-yellow coloured liquid. Complete absorption within 2-3 minutes. Mixing not required.	Dry, clumpy yellow coloured material. Excess N910 visible.	No liquid or dirt released on compression.
I038-A	30	20	Black coloured liquid. Complete absorption into polymer bed, without mixing, within 30 seconds.	Dry, black clumpy material. Excess N910 visible.	No liquid released on compression. Significant staining (dirt) of filter paper observed.
I041-A	30	20	Black coloured liquid. Pooling observed within 30 seconds of oil-polymer contact. Mixing required for complete absorption.	Dry, black clumpy material. Excess N910 visible.	No liquid released on compression. Significant staining (dirt) of filter paper observed.
I045-A	30	20	Dark brown coloured liquid. Pooling observed within 1 minute of oil-polymer contact. Mixing required for complete absorption.	Dry, brown clumpy material. Excess N910 visible.	No liquid or dirt released on compression.
I046-A	30	20	Black coloured liquid. Initial uniform absorption but pooling occurred within 1 minute. Mixing applied. Material appeared very wet following mixing.	Brown/grey clumpy material. Moist in appearance. Excess N910 visible.	Liquid and dirt released on compression.
I049-A	30	20	Dark brown coloured liquid. Pooling observed after 2 minutes. Mixing applied. Material very wet in appearance after mixing. Free liquid visible on sides of vessel.	Brown coloured, clumpy material. Excess N910 visible.	Liquid and dirt released on compression.
I050-A	30	20	Dark brown coloured liquid. Pooling observed after 2 minutes of oil-polymer contact. Mixing applied. Free liquid visible on sides of vessel.	Areas of different colouration visible within polymer bed. Oatmeal textured material (few clumps). Excess N910 visible.	Liquid released on compression.
D015-A	30	20	Yellow coloured liquid. Complete liquid absorption within 30 seconds.	Fluffy yellow coloured appearance. Excess N910 visible.	No liquid or dirt released upon compression.
D022-A	30	20	Pale yellow coloured liquid. Complete liquid absorption within 30 seconds.	Fluffy yellow coloured appearance. Some clumps. Excess N910 visible.	No liquid or dirt released upon compression.



Fig. 1 – Photographs of samples I048-A and I024-A post 24 hours curing.

Table II – Solidification of oil and aqueous wastestreams with N910 & N960 polymer systems

Sample ID no.	Mass of oil (g)	Mass of N910 (g)	Mass of N960 (g)	Observations on absorption	Observations post absorption (after 24 hours curing)	Observations on compression (after 24 hours curing)
I046-A	30	20	0.60	Black coloured liquid. Pooling occurred within 1 minute. Mixing applied.	Material was brown and clumpy in appearance. Excess N910 visible but all N960 consumed.	Small amount of liquid released on compression. Dirt released on compression.
	30	20	1.50	Black coloured liquid. Pooling occurred within 1 minute. Mixing applied.	Material was brown and clumpy in appearance. Excess N910 visible but all N960 consumed.	No liquid released on compression. Dirt released on compression.
I049-A	30	20	0.60	Dark brown coloured liquid. Pooling observed after 2 minutes. Mixing applied. Material moist in appearance after mixing.	Brown coloured, clumpy material. Excess N910 visible. All N960 consumed.	Small amount of liquid released on compression. Dirt released on compression.
	30	20	1.50	Dark brown coloured liquid. Pooling observed after 2 minutes. Mixing applied.	Brown coloured, clumpy material. Excess N910 visible. All N960 consumed.	No liquid released on compression. Dirt released on compression.
I050-A	30	20	0.60	Dark brown coloured liquid. Pooling observed after 2 minutes of oil-polymer contact. Mixing applied.	Pale brown, oat-meal material with no clumps. Excess N910 visible. All N960 consumed.	Small amount of liquid released on compression. Dirt released on compression.
	30	20	1.50	Dark brown coloured liquid. Pooling observed after 2 minutes of oil-polymer contact. Mixing applied.	Pale brown, oat-meal material with some clumps. Excess N910 visible. All N960 consumed.	No liquid released on compression. Dirt released on compression.

**Table III – Solidification of oil wastestreams with N910 polymer at multiple ratios**

Sample ID no.	Oil to N910 ratio (w/w)	Observations on absorption	Observations post-absorption (after 24 hours curing)	Observations on compression (after 24 hours curing)
I018-A	2:1	Brown coloured liquid. Pooling of liquid observed after two minutes. Mixing applied.	Brown, clumpy material. Excess N910 visible.	No liquid released on compression. Some dirt released on compression.
	3:1	Brown coloured liquid. Pooling of liquid observed after two minutes. Mixing applied.	Brown, clumpy material. Excess N910 visible.	No liquid released on compression. Some dirt released on compression.
	5:1	Brown coloured liquid. Mixing applied. All N910 consumed.	Dark brown coloured, clumpy material. Some wet patches on the polymer bed. No excess N910 visible.	Liquid and dirt released on compression.
	10:1	Brown coloured liquid. All N910 consumed with a large excess of oil.	Sludge of absorbed polymer with free liquid oil.	Liquid present in sample – compression not applied.
I024-A	2:1	Brown-yellow coloured liquid. Complete absorption within 30 seconds.	Dry, clumpy yellow coloured material. Excess N910 visible.	No liquid or dirt released upon compression.
	3:1	Brown-yellow coloured liquid. Pooling on surface of polymer bed within 2 minutes. Mixing applied.	Dry, clumpy yellow coloured material. Excess N910 visible.	No liquid or dirt released upon compression.
	5:1	Brown-yellow coloured liquid. Pooling on surface of polymer bed within 2 minutes. Mixing applied. Virtually all N910 consumed.	Yellow, sticky material. Some excess N910 visible.	Small amount of liquid released on compression.
	10:1	Brown-yellow coloured liquid. All N910 consumed with a large excess of oil.	Yellow coloured, jelly-like material.	Liquid present in sample – compression not applied.
I038-A	2:1	Black coloured liquid. Pooling observed after 2 minutes. Mixing applied.	Black coloured, clumpy material with excess N910 visible.	Dirt released on compression. No release of liquid.
	3:1	Black coloured liquid. Pooling observed after 2 minutes. Mixing applied.	Black coloured, clumpy material with excess N910 visible.	Dirt released on compression. No release of liquid.
	5:1	Black coloured liquid. Pooling observed after 2 minutes. Mixing applied. All N910 consumed.	Black coloured, clumpy material.	Liquid released on compression.
	10:1	Black coloured liquid. All N910 consumed with a large excess of oil.	Black sludge of absorbed polymer with free liquid oil.	Liquid present in sample – compression not applied.

**Table III – Solidification of oil wastestreams with N910 polymer at multiple ratios (continued)**

Sample ID no.	Oil to N910 ratio (w/w)	Observations on absorption	Observations post-absorption (after 24 hours curing)	Observations on compression (after 24 hours curing)
D015-A	2:1	Yellow coloured liquid. Pooling observed after 2 minutes. Mixing applied.	Dry, clumpy yellow coloured material. Excess N910 visible.	No liquid or dirt released upon compression.
	3:1	Yellow coloured liquid. Pooling observed after 2 minutes. Mixing applied.	Dry, clumpy yellow coloured material. Excess N910 visible.	No liquid or dirt released upon compression.
	5:1	Yellow coloured liquid. Pooling observed after 2 minutes. Mixing applied. All N910 consumed.	Yellow, sticky material. Some excess N910 visible.	Small amount of liquid released on compression.
	10:1	Yellow coloured liquid. All N910 consumed with a large excess of oil.	Yellow coloured, jelly-like material.	Liquid present in sample – compression not applied.
D022-A	2:1	Pale yellow coloured liquid. Rapid absorption into polymer bed.	Dry, clumpy yellow coloured material. Excess N910 visible.	No liquid or dirt released upon compression.
	3:1	Pale yellow coloured liquid. Absorption into polymer bed within 2-3 minutes.	Dry, clumpy yellow coloured material. Excess N910 visible.	No liquid or dirt released upon compression.
	5:1	Pale yellow coloured liquid. Pooling observed after 3 minutes. Mixing applied. All N910 consumed.	Yellow, sticky material. Some excess N910 visible.	Small amount of liquid released on compression.
	10:1	Pale yellow coloured liquid. All N910 consumed with a large excess of oil.	Yellow coloured, jelly-like material.	Liquid present in sample – compression not applied.



**Fig. 2 - Photograph of multiple oil / polymer ratios employed for sample D018-A post 24 hours curing.**

Notes:

1. There were differences in the environmental temperature throughout the duration of the experimental campaign. Samples I041-A, I049-A and I050-A were tested at a temperature of 6°C; samples I045-A, I046-A, I024-A and I038-A were tested at a temperature of 10°C; samples I018-A, D015-A and D022-A were tested at a temperature of 14°C.
2. Mixing of the polymer must be undertaken at a slow, steady rate to ensure that the polymer structure is not broken up and to ensure adequate contact between the polymer and the liquid.
3. The rate of addition of the liquid to the polymer bed must be slow and even, ensuring full coverage of the polymer bed surface, to ensure uniform absorption.

## **DISCUSSION & INTERPRETATION**

The results of the small-scale experimental program illustrate that Nochar N910/N960 polymer systems have proved effective in the immobilization of waste oil into a solid polymeric product, with no leaching of liquid on compression.

The key aspect of the process of oil solidification using this polymer system is the degree of contact between the polymer and the liquid wastestream. Process parameters relating to addition and mixing have the greatest impact on this. The experimental campaign showed that uniform absorption of the liquid wastestream onto the polymer bed was achieved using a slow, even rate of addition of liquid to the polymer to ensure full coverage of the polymer bed surface. Mixing of the polymer / oil mixture was found to work best at a slow, steady rate which ensured that the polymer structure was not disrupted and that adequate contact between liquid wastestream and polymer was maintained. The nature of the polymer bed is another parameter which has an impact on the success of the solidification. Pre-weighing of the oils and polymer enables control of the oil/polymer ratio to be maintained. Pre-blending of the polymer bed and agitation to ensure even blending and to prevent agglomeration of the polymer are key to successful solidification. The learning with respect to these process parameters was fed into the ongoing bench-scale experimental campaigns and will be considered in any large scale campaign.

A key point arising from this experimental program, and thus learning for any larger scale experimental program, is the need to test for compatibility and to assess the appropriate oil / polymer ratio on a case by case basis. The waste oil held on the Sellafield site is chemically and physically diverse, and the experimental results have illustrated that each wastestream is unique in its composition and behaviour. As such it is appropriate to undertake this testing for each separate wastestream.

The testing of the range of oil to polymer ratios have indicated that immobilization of the liquid wastestreams can be effected by a range of ratios. The 1.5:1 ratio employed was effective for the majority of the wastestreams tested (with or without the addition of N960 polymers). The polymer testing indicated that polymer ratios of up to 5:1 were effective in liquid immobilization but ratios greater than this (namely 5:1 and 10:1) did lead to incomplete liquid immobilization. On this basis, it could be considered that a 2:1 ratio for oil is the optimum ratio for both economic considerations and for security of the

solidification. A 1:1 ratio adds a safety factor to the waste solidification, in that there is a significant quantity of unreacted N910 polymer remaining after solidification. Whilst this would prove not cost-effective, this ratio may be mandated by some government agencies owing to the additional security factor. The 3:1 ratio will essentially consume the polymer's capacity for liquid and thus should be considered as an "outer limit" for the security of the solidification.

Age of the wastestream was shown not to influence the performance of the polymers but that curing time can be affected by wastestream age – the newer oils were demonstrated to cure more quickly than the older wastestreams. The results demonstrate that the polymer products selectively bond with the hydrocarbon elements of the material. Some dirt present in the liquid can be absorbed into the polymer, if it is of a suitable molecular size to be absorbed through the pores of the polymer. Any 'dirt'-type contamination too big to be absorbed through the polymer pores is not absorbed into the polymer structure.

The experimental work undertaken in January 2006 and that during October/November 2006 has indicated that low temperature did not have any adverse effects on the performance of the polymers. In the case of low temperature systems, curing time is again affected for some wastestreams and a typical cure time of 24 hours is extended to 48-72 hours for complete curing for such wastestreams.

The experimental program undertaken has demonstrated a potential use for the polymer systems as a methodology for general indicative analysis of the chemical nature of an unknown sample. Testing in this way would demonstrate whether a material is organic or aqueous or a mixture, in the absence of complete chemical characterization. This testing has also proved the presence of additional chemical contaminants in particular wastestreams – for example, if solidification of a wastestream with a N910/N960 polymer blend was incomplete, this would indicate the presence of an additional non-hydrocarbon, non-aqueous component. In the absence of complete waste characterisation, the information that this indicative analysis can provide may prove particularly useful in expanding our knowledge of the chemical composition of wastestreams.

## **CEMENTATION**

There are requirements under the UK Conditions for Acceptance for LLW disposal, in addition to radiological requirements, under which a waste form must meet a minimum unconfined compressive strength of 400 kN/m<sup>2</sup> and meet the requirements of a designated leach test. On this basis, it was considered that cement encapsulation of the solidified oil wastestream would prove to be a suitable waste form for final disposal.

To this end, concurrent with the bench-scale compatibility trials being undertaken at Sellafield, cement encapsulation trials on non-radioactive simulants were undertaken by NSG Environmental Ltd on behalf of Waste C&C. The testing regime at NSG Environmental Ltd involved the direct cement encapsulation of a number of oil types to form a solidified mass. This testing demonstrated that polymer solidified oil and grout can form a safe, non-compactable matrix suitable for final disposal. A provisional

formulation envelope was developed for the encapsulation of solidified oil through this experimental campaign.

Final protocols for cement encapsulation require further investigation. The final package form required to meet the UK Conditions for Acceptance for LLW disposal is yet to be formally down-selected, although given the requirements of these Conditions for Acceptance it is anticipated that cement encapsulation will be required in some form. The suitability of waste package forms against the requirements of the Conditions for Acceptance requires consideration in the project. Process parameters for any cement encapsulation process require further investigation; for example the curing time required for complete solidification of the oil-polymer matrix prior to grouting. The nature of any additional testing campaign will be directed by the waste package type selected for final disposal.

### **CONCEPTUAL METHODOLOGY FOR FULL-SCALE TRIAL**

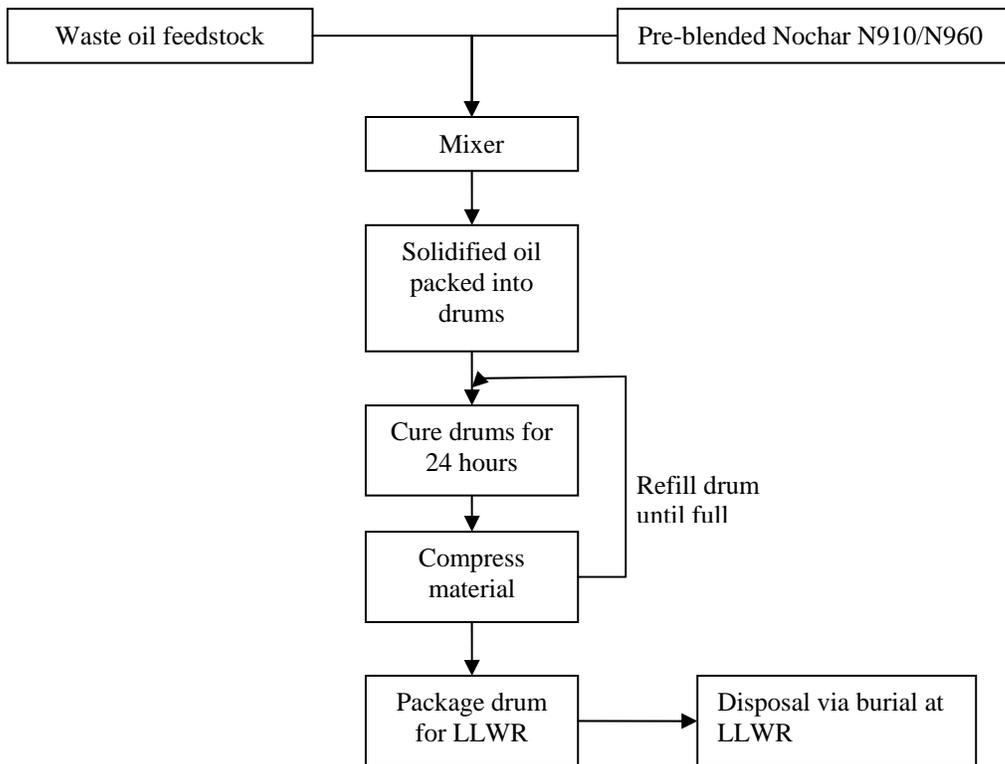
The experimental program undertaken during 2006 involved assessing the ability of the Nochar polymer systems to effect the complete immobilization of a range of hydrocarbon based wastestreams. This work was undertaken to support an innovative treatment and disposal solution for waste oils other than incineration. It is the intention of Waste C&C to translate this work into a large scale trial to test both the practical/logistical aspects of undertaking large scale immobilization and also to test the waste route to the nearby LLWR. Whilst the methodology for such a full scale solidification process is yet to be determined, there is learning that can be extracted from the small-scale trial program which will inform this methodology.

A low cost, simplified process for the large scale trial and for any future bulk process is preferred for both economic and logistical reasons. In broad terms, the process for the large scale trial / bulk scale process will be a scaled up version of the small scale trial. It is envisaged that such a large scale trial – involving the solidification of some 2-3m<sup>3</sup> of contaminated oil – will take place in early 2007.

The small-scale experimental program has indicated the need for, and indeed the usefulness of, conducting small-scale experiments on each wastestream to be included in any large scale trial prior to large-scale solidification. This is to enable process parameters such as optimum mixing time, optimum mixing speed, the most appropriate oil to polymer ratio, compression times and curing times. This additional small scale testing will prove essential to the success of the trial – the key to the success of the solidification process is the phase boundary between the liquid and the polymer. Evidently parameters such as mixing speed, mixing time and oil to polymer ratio will have significant impacts on the phase boundary and will have thus great impact on the success of the solidification.

Figure I illustrates a conceptual methodology for the large scale trial to the LLWR. It is anticipated that the methodology will closely reflect the method applied for the small-scale trials. Small-scale testing of a wastestream for the large scale trial will be undertaken to establish the process parameters. On the basis of the results of this small-

scale testing, the Nochar for the solidification will be pre-blended in the appropriate ratio. The selected ratio will incorporate a safety factor in that there will be an excess of N910 polymer present, to provide reassurance mitigation against any incomplete solidification. The contaminated waste oil to be solidified and the polymer for the experiment will be pre-weighed, to provide assurance that the proper bonding ratio will be obtained, and then combined in a paddle mixer. The material will be mixed at a pre-determined speed for a pre-determined duration until complete liquid absorption is obtained. The solidified oil will then be packed into drums and allowed to cure for 24-48 hours. When curing is complete, the material will be compressed to remove air voids that exist in the matrix (although it is expected that the weight of the oil will compress the solidified material itself to some degree during the curing process). The process of immobilisation will then be repeated and the drums re-filled, cured and compressed until the drum is full. The drum will then be packaged as required to meet the requirements of the LLWR before being transported to the LLWR for disposal via burial.



**Figure 3 – Conceptual methodology for large-scale Nochar solidification trial**

There are a number of options under consideration for the final packaging of the immobilised wastestream for transport to and disposal at LLWR. The final choice of package will be driven by the requirements of the LLWR and regulatory requirements.

The options available for final packaging of the material include:

- Direct disposal of the solidified material to a drum or box.
- Encapsulation of the solidified material in a drum or box using encapsulation agents.
- Encapsulation of the solidified material in grout lined drums or boxes.

- Direct grouting of the solidified material within the drum or box.

The requirements of the LLWR push the choice of final packaging option to the latter two options. The nature of this final packaging is yet to be determined.

## CONCLUSIONS

On the basis of the results of the small-scale experimental program, a number of conclusions can be drawn:

- Nochar polymer systems were effective in the immobilisation of liquid hydrocarbon wastestreams into a solid polymeric matrix, with no leaching of liquid on the application of light compression.
- Oil to polymer ratios of 1.5:1, 2:1 and 3:1 (w/w) have been demonstrated to be successful at the immobilization of hydrocarbon wastestreams. For safety and economic reasons, a ratio of 2:1 oil to polymer (w/w) is the most appropriate, although requirements from the LLWR may mandate a 1:1 ratio.
- The method of addition of oil to polymer and the method of mixing is critical to the success of the immobilization process. Wastestreams must be added at a slow, steady rate to the polymer bed and care must be taken to ensure that maximum coverage of the polymer bed is obtained. Mixing must ideally be slow and comparatively low force in order to prevent break-up of the polymer structure.
- Low environmental temperature was found to have no adverse effect on the success of the solidification process, other than increasing the time required for complete curing of the solidified material.
- The timescale for complete polymer curing has a dependence on the relative 'cleanliness' of the oil wastestream. Dirtier oils tended to require a longer period for curing than cleaner oils.
- The small-scale trials have identified a number of implications for any scaled-up process. This program has identified that careful measurement, through small-scale testing, of process parameters is vital to ensure the success of any large scale process.
- The testing undertaken on cement encapsulation by NSG Environmental Ltd on behalf of Waste C&C has demonstrated that cement encapsulation of polymer solidified oil can produce a waste form suitable for disposal via burial as LLW.
- Whilst the bulk scale methodology is yet to be determined, the results of the small-scale trial program have been used to produce a conceptual large-scale trial methodology.

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