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ABSTRACT

Decision makers involved with hazardous waste treatment issues are faced with the challenge of making objective evaluations concerning treatment formulations. Such evaluations are driven by the need to balance regulatory concerns (EPA and State treatment standards) with economic realities (treatment and disposal costs). Waste treatment data is often gained through treatability studies that precede final treatment activities. To develop a dependable approach for assessing treatment data, there are several criteria that must be considered: solid mathematical basis; easy to understand and utilize; incorporates applicable, prevailing treatment standard(s); usable for several treatment types; applicable to multiple hazards, etc. In meeting these criteria, the evaluation method will be steered onto more solid quantitative footing, and steered away from qualitative conjecture.

This work utilizes an *effectiveness factor* (denoted as η) as the basis for waste treatment evaluations, which was recently developed for application to mixed waste treatability studies involving solidification and stabilization at the Idaho National Engineering and Environmental Laboratory. The effectiveness factor incorporates an arbitrary treatment criterion Φ , which in practice could be the Toxicity Characteristic Leaching Procedure, Unconfined Compressive Strength, Leachability Index, or any other criterion used to judge treatment performance. Three values for Φ are utilized when assessing a given treatment formulation: before treatment, after treatment, and a reference value (typically a treatment standard). The expression for η also incorporates the waste loading as the prime experimental parameter, and accounts for the contribution that each hazard has upon the overall treatment performance. Also discussed are general guidelines for numerical boundaries and statistical interpretations of treatment data.

Case studies are presented that demonstrate the usefulness of the effectiveness factor and related numerical methods, where the typical hazards encountered are toxic metals within mixed waste. Trends are observed that indicate favorable treatment (positive η values), marginal treatment (near-zero positive η values), and unacceptable treatment (negative η values). Optimal treatment formulations can be determined for some wastes by careful examination of η values, since η may peak at a specific waste loading. The effectiveness factor could be adopted as a decision making tool for the treatment of mixed waste and non-radioactive hazardous waste within the DOE complex and the Private Sector. As such a tool, η would add a level of confidence to decisions regarding waste treatment formulations.

INTRODUCTION

National Laboratories within the DOE complex are involved in making informed decisions concerning the choice of final or full-scale treatments for hazardous and low-level mixed waste (LLMW). Decisions tied to waste treatment should incorporate an element of mathematical certainty as to the performance (effectiveness) of proposed treatment formulations. The effectiveness of a treatment can often be correlated by considering one or more key experimental parameters with one or more treatment criteria. An expression for an *effectiveness factor* η is discussed herein, as based on fundamental concepts and quantities related to performance measures of waste treatment. The expression for η is written in general terms to allow the use of virtually any treatment criterion. This

work follows the founding paper written on the effectiveness factor (1), providing further mathematical developments and more case studies.

Lab-scale treatability studies are a common method to investigate a treatment matrix on a given waste, wherein experimental parameters are employed so that their effect upon performance criteria can be assessed. The mathematical approach developed for the effectiveness factor utilized as a testbed experimental data from treatability studies at the INEEL spanning six years, as summarized by Gering and Schwendiman (2), Gering *et al.* (3,4,5) and Tyson and Schwendiman (6), wherein hydraulic binders and an epoxy binder were used. Waste loading (given as mass fraction LLMW in the treated form) is used as the key parameter, and results from the Toxicity Characteristic Leaching Procedure (TCLP) are used as indicators of treatment effectiveness (7). TCLP values used include those for the untreated LLMW, treated forms, as well as the applicable treatment standard values (8,9). Hydraulic binders have been predominately used in the above INEEL treatability studies, most notably Portland cement (PC). Where feasible, the performance of other binders are compared with that of Portland cement.

This paper will focus on LLMW materials that contain hazardous metals (e.g., lead, cadmium, chrome, mercury, etc.), although the general concepts and derivations are applicable to any chemical hazard (including organic constituents) and radioactive hazard, and will accommodate practically any quantifiable treatment criterion. In addition, treatment performance with regard to multiple hazards within a single waste can easily be assessed with the effectiveness factor.

MATHEMATICAL APPROACH

Foundational Development

To develop the expression of the effectiveness factor, we begin by considering an arbitrary treatment criterion, denoted as Φ . The Φ criterion chosen for this work is the TCLP test (7). Alternately, Φ could be one of many other criteria that represent a change in waste performance resulting from treatment, such as porosity, leachability index, compressive strength, etc. Notations for Φ terms pertaining to before treatment, Φ_b , after treatment, Φ_a , and a reference value, Φ_r , are used here as a convenience. Expressions involving Φ_a , Φ_b , and Φ_r must have a physical basis or meaning to have mathematical validity. Three such expressions are combined to form the overall expression for the effectiveness factor. As a matter of mathematical convention, it is assumed here that effective waste treatment will produce Φ_a values that are less than those of Φ_b , i.e. it is desirable to achieve diminishing values of Φ_a . The full expression of the effectiveness factor that was derived in the founding paper (1) is given as follows

$$\eta = \frac{X_{Waste}}{2n} \sum_{i=1}^n \left[\underbrace{\frac{(\Phi_b - \Phi_r)}{\Phi_b}}_{(I)} \left(\underbrace{\frac{(\Phi_b - \Phi_a)}{\Phi_b}}_{(II)} + \underbrace{\frac{(\Phi_r - \Phi_a)}{\Phi_r}}_{(III)} \right) \right] \quad (1)$$

where n is the total number of hazardous components present in the waste and X_{waste} is the mass fraction of waste within the treated form (to account for waste dilution due to treatment). Term I represents the minimum required change that Φ must undergo (due to treatment) to meet or exceed the reference value, term II is the net change in Φ due to treatment, and term III is the departure of Φ_a from the reference value. These three terms have been normalized by dividing by appropriate Φ values in order to define mathematical limits.

The waste mass fraction for a generic solidification formulation is expressed as

$$X_{Waste} = \frac{\text{Mass Waste}}{\text{Mass Waste} + \text{Mass Dry Binder} + \text{Mass Additives} + \text{Mass Added Water}} \quad (2)$$

The theoretical maximum value of η is unity as X_{waste} approaches unity and as Φ_a and Φ_r tend toward zero. In practice, however, positive values for η will fall mostly within the range from 0.1 to 0.7. Larger positive values for η indicate a greater effectiveness in waste treatment, whereas a near-zero or negative values may occur if a treatment has produced a detrimental effect ($\Phi_a \geq \Phi_r$) upon the leaching of hazardous components. Positive values for η will never exceed X_{waste} , so the waste mass fraction serves as an important upper bound. As will be seen later, the difference ($X_{waste} - \eta$) is useful to determine when treatment performance starts to decrease due to excessive waste loading within the treatment formulation.

It should be noted that Eq. 1 accounts for waste loading, multiple hazardous constituents, treatment standards for each constituent, and each treatment standard basis. Equation 1 balances regulatory concerns with economic concerns by considering how well a treatment has met the prevailing treatment criteria at a given waste loading, as disposal costs (directly related to waste loading) can predominate overall treatment costs in some cases.

An additional comment is in order concerning the convention that has been chosen for the criterion Φ , that is, that Φ show a decrease when effective treatment has been achieved. There are criteria for which Φ would show an *increase* upon successful treatment, for example, compressive strength. For such cases it is recommended that Φ be defined as the *inverse* value of the criterion. Once this is done, Eq. 1 is directly applicable to the chosen Φ .

Useful Mathematical Boundaries

The effectiveness factor can be made more practical and meaningful by considering two mathematical boundaries that give further insight in treatment performance. The first boundary is the *minimum value that η can have while still passing all treatment criteria* (η_{min}), while the second boundary is the *maximum η value at which one treatment standard is barely exceeded* (η_{max}). These boundaries are defined for each waste at a given waste loading, and collectively define a gray area between them of treatment performance where some treatments pass the applicable treatment standards, while others fail. Above the η_{max} boundary all treatments pass the prescribed standards, while below the η_{min} boundary all treatments fail. Graphical representations of these bounds are given in a following section.

The expression for $\eta_{\min}$ is obtained by considering the special case that Φ_a equals Φ_r for all hazardous constituents within a treated waste, that is, that all treatment standards have been sparingly met. Under these conditions the expression from Eq. 1 becomes

$$\eta_{\min} = \frac{X_{\text{waste}}}{2n} \sum_{i=1}^n \left[\frac{(\Phi_b - \Phi_r)}{\Phi_b} \right]^2 \quad (3)$$

Determining values for $\eta_{\max}$ is not as straightforward, as it requires a comparative screening of η values that are derived by allowing only one hazardous constituent at a time to have Φ_a equal Φ_r , while all the other Φ_a are artificially set equal to zero.

Some general comments should be made concerning $\eta_{\min}$ and $\eta_{\max}$. First, these boundaries are lines within η versus X_{waste} plots where $\eta_{\max}$ always lies above $\eta_{\min}$ for a waste containing multiple hazards, whereas $\eta_{\min}$ and $\eta_{\max}$ are the same line for a waste containing a single hazardous constituent. Second, these boundaries always lay below the line that defines the upper limit for η , where $\eta = X_{\text{waste}}$. Lastly, the position and magnitude of these boundaries are determined by the applicable treatment standards, the characteristics of the raw untreated waste, and are directly proportional to the waste loading of the treated waste.

Statistical Considerations

Statistical interpretations of the calculated η values are done by considering the standard deviation of the η values from the "reference line" that serves as the upper limit for η (where $\eta = X_{\text{waste}}$). The expression for the standard deviation (s) for our application is

$$s = \sqrt{\frac{\sum_{i=1}^n (X_{\text{waste}} - \eta)_i^2}{n - 1}} \quad (4)$$

Lower values of s (say, less than 0.5) are desirable for each set of treatment data of a particular waste; such values infer consistently favorable treatment has been attained over the range of X_{waste} that was considered. Larger values of s (e.g., greater than 1) denote a partial or overall failure of the treatment, as η has experienced deviations from the theoretical upper limit that were too large.

RESULTS AND DISCUSSION

Treatment information from selected mixed wastes served as the raw data for η calculations. Three wastes are discussed herein: INEEL 147A, NAVY MI-W003 and INEEL 426, where the hazards in these mixed wastes are primarily due to toxic metals. Summary treatment results are given in Tables 1 through 3, and applicable treatment standards for toxic metals are given in Table 4.

Treatment standards considered herein are those defined by the Resource Conservation and Recovery Act (RCRA) and the Universal Treatment Standards (UTS). In this paper "RCRA" is used to denote characteristic-only wastes that carry EPA 'D' codes (e.g., D006 for cadmium).

Most treatment formulations represented herein contained either Type I&II Portland cement (PC), epoxy, or phosphate-bonded ceramic (PBC) as the primary binder. Small amounts of additives were used in some formulations in an effort to improve treatment performance. Noteworthy additives used in this work include hydrated lime, sodium sulfide, and a white glue (used when a mixed waste was known or suspected of having a significant percentage of organic components, e.g., paint chip waste).

Figures 1 through 4 contain η values for the three mixed wastes mentioned above. Overall, the figures demonstrate that the effectiveness factor gives a good indication for the performance of a treatment formulation, accurately indicating the trends of the best treatments (positive η values), little or no treatment (near-zero values), and undesirable treatment (negative values).

Figure 1 contains plots of η values obtained from the PC-based treatability study performed on INEEL 147A, an incinerator flyash from the Waste Experimental Reduction Facility (WERF) at the INEEL. TCLP analysis for the raw, untreated waste gave antimony at 3.89 mg/L, cadmium at 48.7 mg/L, lead at 37.4 mg/L, and silver at 0.343 mg/L. The TCLP values used for η calculations for INEEL 147A were obtained from Table 1. A comparison is made in Fig. 1 between choosing RCRA or UTS as the regulatory (treatment) standard. Effectiveness factor values in Fig. 1 were derived for both a RCRA and a UTS basis because this flyash mixed waste can have RCRA or UTS-related hazardous components, depending on the nature of the feed stock entering the WERF incinerator. The composite raw waste samples made for 147A contained both RCRA and UTS portions, thereby requiring the entire composites to fall under UTS. As such, tougher treatment standards had to be met for the treated waste forms, and an additional UTS metal, antimony, was added to the list of toxic metals. Figure 1 shows that PC-based treatments are effective in meeting RCRA standards (all $\bullet$ values shown are above the $\eta_{\max}$ line), yet display a significant drop in treatment performance when UTS is invoked (all $\blacksquare$ values shown are below the $\eta_{\max}$ line). Under RCRA, six of eight PC-based formulations provide satisfactory treatment (two are off-scale negative values at higher waste loadings) for waste loadings between 27 to 37% by mass, whereas only a single formulation yields satisfactory treatment under UTS (waste loading 28.4%). Another interpretation of the treatment data can be done using a standard deviation (Eq. 4), where PC treatments under RCRA have a standard deviation of 0.963, but under UTS the standard deviation is 4.37. One obvious conclusion from Fig. 1 is that flyash under RCRA should be segregated and treated separately from UTS flyash; this practice will ensure that a higher percentage of treated WERF flyash will meet the applicable treatment standard.

The treatment performance of PC formulations are compared with those obtained from PBC in Fig. 2 for the treatment of INEEL 147A. Because UTS is the regulatory standard for this mixed waste (per sample composites), the UTS-derived values for the PC treatments ($\blacksquare$ symbols) are the same as those given in Fig. 1. Overall, it is seen that neither PC or PBC provide consistently satisfactory treatment of the 147A flyash, although there appears to be slightly better performance in the PC-based formulations as reflected by values of the standard deviations (see Eq. 4). PC treatments gave

a standard deviation of 4.37, whereas PBC treatments resulted in a standard deviation of 7.07, albeit the PBC recipes extended to higher waste loadings. Figure 2 indicates that no acceptable treatment scenario exists for either PC or PBC for waste loadings exceeding 35%. Further research is recommended before PC or PBC treatment formulations are used to treat WERF flyash on a full-scale (drum-scale) basis.

Results for the effectiveness factor are also given herein for PC and epoxy-based solidification of a paint chip waste from the Mare Island Naval Shipyard, MI-W003, that contains cadmium and chromium at 3.1 mg/L TCLP and 240 mg/L TCLP, respectively. TCLP values for treated forms of NAVY MI-W003 are given in Table 2. Epoxy stabilization for other types of mixed waste is discussed in Gering *et al.* (3,4,5) and Tyson and Schwendiman (6). The epoxy binder for these studies consisted of Dow Chemical D.E.R. 324 resin and the curing agent Pacific Anchor/Air Products Ancamide 502. The η values shown in Fig. 3 were derived from the treatment data given in Table 2. Figure 3 shows that epoxy provides excellent stabilization for this mixed waste (all but one η value is above the η_{max} line), whereas PC treatments failed in most cases to meet the treatment standards for cadmium and chromium, as seen by the high percentage of η values below the η_{min} line. The standard deviation for epoxy-based treatments is 0.183, but increased to 1.17 for PC treatments. Similar stabilization results were obtained for other paint chip wastes studied in FY 1997 (3). Although the epoxy binder may be acting more as a physical or mechanical micro/macro-encapsulant (providing little *chemical* stabilization to the toxic metals), it provides a very effective mechanism for binding with the organic matrix that comprises the paint chips, and there appears to be a slight benefit in particle size reduction as a pretreatment step. In contrast, the PC-based formulations appear to provide little if any binding mechanism between the hydraulic binders and the paint chip media.

INEEL 426 (TURCO decontamination waste) is a LLMW under UTS because it carries a D001 code as an ignitable/oxidizer material. This waste is composed of KOH, K_2CrO_4 , and KMnO_4 , where the untreated mass contains 4500 mg/kg chromium. Values for the effectiveness factor are listed and plotted in Table 3 and Figure 4, which show the dramatic beneficial effect of additives on concrete performance as assessed through TCLP testing. Additives (e.g. ferrous chloride) were used *in-situ* within the concrete mixture to neutralize the KMnO_4 and to reduce the hexavalent chrome to Cr^{3+} . Table 3 and Figure 4 clearly show that the PC mixtures with the additives provide η values that are very close to the reference line, whereas all monoliths lacking additives produce negative η values that quickly decrease as the waste loading increases. These results imply that the waste loading could be increased far beyond 15% provided the same additives are employed.

Some general comments are in order for the results seen in the aforementioned figures. First, the highest value for waste loading does not always provide the best/highest value for the effectiveness factor, nor does the lowest waste loading equate to the worst value for η . Although the expression for η (Eq. 1) shows a direct proportionality to the waste mass fraction, η is clearly performance driven, depending heavily on the behavior of the chosen criterion Φ .

Secondly, negative values for η will always denote unsatisfactory treatment formulations; however, small positive values may or may not reflect desirable treatments. A treatment can yield a positive η value while failing one or more treatment standards, which is understood by considering the relative

contributions to Eq. 1: term II can be positive while term III is negative. This scenario can occur if one or more treatment standards are not met by a small amount in the treated waste form. If the magnitude of these two terms are such that term II is greater than term III, then a small positive η will arise. This "gray area" of treatment performance is aptly defined and understood by considering the $\eta_{\min}$ and $\eta_{\max}$ boundaries shown in each figure. Care should always be exercised in checking if a treatment standard(s) has been met for a given treatment formulation before it is assumed that a positive η value relates to a treatment that produces a non-hazardous waste material.

Lastly, utilization of the effectiveness factor is not limited to hazardous metals, but rather, can be applied to any quantifiable chemical (inorganic and organic) and radiological hazard as long as a treatment criterion (Φ) can be assigned to the hazard. For example, the leachability index (10) can be used to measure the leachability of radioisotopes from radioactive waste.

CONCLUSIONS AND RECOMMENDATIONS

This work has presented a solid mathematical basis to assess waste treatment performance, rather than relying on guesswork, overly conservative approaches (that result in unnecessarily high disposal costs), or qualitative guidelines. The effectiveness factor has been demonstrated as a tool for informed decision making with regard to hazardous and mixed waste treatment, based on common, readily available data pertinent to waste treatment (TCLP). This factor is versatile in that it can be used for any solidification/stabilization system, whether it be based on hydraulic binders, thermoplastic binders, thermoset binders, etc., and it can be based on virtually any arbitrary treatment criterion that relates to a particular aspect of treatment performance (e.g., leachability, compressive strength, porosity, etc.).

Results contained in this work have confirmed the usefulness of the effectiveness factor for evaluating treatment performance on INEEL mixed wastes. Values for η clearly indicated the following trends: the highest positive values represent preferred treatments, positive near-zero values are usually not desirable due to one or more treatment standard that has been missed by a narrow margin, and negative values are never desirable because they indicate a treatment formulation that has significantly failed one or more treatment standards.

The development presented herein can benefit decision-makers within the DOE National Laboratory complex, as well as other Government agencies (e.g., Department of Defense) and the Private Sector. The effectiveness factor can be used to determine optimal treatment formulations for a given waste and treatment method, and is an excellent tool for comparing the performance of various treatment methods being considered for a waste. As such, η would add a level of confidence to decisions regarding waste treatment methods, treatment formulations and final waste disposal.

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Table 1. Treatability study results for solidified monoliths of INEL 147A, *WERF flyash* (Treatment Standard: UTS).

Monolith Code	Waste Loading, wt%	Binder	Sb	Cd	Pb	Ag	η
<i>147A Raw Waste</i> <i>TCLP, mg/L</i>	<i>(100)</i>	<i>none</i>	<i>3.89</i>	<i>48.7</i>	<i>37.4</i>	<i>0.343</i>	<i>----</i>
147A.S.HC1	29.9	PC	≤0.0032	0.0017	1.19	≤0.0009	0.072
147A.S.HC2	40.0	PC	≤0.0032	10.6	42.5	0.0058	-8.275
147A.S.HCA1	28.2	PC	0.0033	0.0022	1.26	≤0.0009	0.061
147A.S.HCA2	36.8	PC	0.0166	0.336	0.136	≤0.0009	0.138
147A.S.HCA3	26.7	PC	0.0036	0.0024	0.987	≤0.0009	0.082
147A.S.HCA4	32.9	PC	0.0036	0.0017	0.657	≤0.0009	0.138
147A.S.HCA5	28.4	PC	0.0048	0.0021	0.298	≤0.0009	0.154
147A.S.HCA6	37.5	PC	≤0.0032	9.42	40.9	0.0034	-7.264
147A.S.PBC1	41.7	PBC	9.47	0.610	0.231	0.112	-0.103
147A.S.PBC2	41.7	PBC	6.25	0.689	0.303	0.076	-0.077
147A.S.PBCA2	41.3	PBC	5.78	0.449	0.0632	0.100	0.030
147A.S.PBC3	25.0	PBC	3.79	0.023	0.0101	0.0358	0.115
147A.S.PBC3D	25.0	PBC	3.35	0.022	0.0055	0.0389	0.120
147A.S.PBC4	60.0	PBC	6.77	17.8	11.0	0.177	-9.052
147A.S.PBC5	50.0	PBC	5.36	2.90	0.638	0.326	-0.869
147A.S.PBC6	70.0	PBC	8.36	28.1	10.5	0.515	-15.256

Shaded areas indicate TCLP values that fail the treatment standard for the indicated metal.

≤ Value is at or below the Instrument Detection Limit (IDL).

Table 2. Treatability study results for solidified monoliths of Navy MI-W003, *Paint Chips with Heavy Metals* (Treatment Standard: RCRA).

Monolith Code	Waste Loading, wt%	Binder	Cd	Cr	η
MI-W003 Raw Waste TCLP, mg/L	(100)	none	3.1	240	---
As-Is Waste ("S") MIW003.S.HC1	15.4	PC	≤ 0.0025	41.8	-0.194
MIW003.S.HC2	25.9	PC	≤ 0.0025	8.84	0.100
MIW003.S.HC3	39.6	PC	≤ 0.0025	87.9	-1.412
MIW003.S.HC3D	39.6	PC	≤ 0.0031	84.7	-1.349
MIW003.S.PT1	36.4	PC	≤ 0.0031	73.8	-1.040
MIW003.S.PT2	24.7	PC	≤ 0.0031	70.1	-0.661
MIW003.S.HCA1	14.8	PC	≤ 0.0031	2.49	0.104
MIW003.S.HCA2	25.8	PC	≤ 0.0031	13.4	0.041
Size-reduced Waste ("S2") MIW003.S2.HC1	14.9	PC	≤ 0.0025	1.83	0.110
MIW003.S2.HC2	26.0	PC	≤ 0.0025	63.8	-0.613
MIW003.S2.HC3	39.3	PC	≤ 0.0025	89.7	-1.435
MIW003.S2.PT1	36.4	PC	≤ 0.0031	78.2	-1.120
MIW003.S2.PT2	24.7	PC	0.0041	70.1	-0.661
W003MS01TI	30.0	Epoxy	≤ 0.0025	0.886	0.235
W003MS02TI	40.0	Epoxy	0.0140	2.81	0.274
W003MS03TI	50.0	Epoxy	0.0200	1.89	0.365
W003MS04TI	60.0	Epoxy	0.0340	8.07	0.250
Size-reduced Waste W003MS05TI	30.0	Epoxy	≤ 0.0025	0.852	0.236
W003MS06TI	40.0	Epoxy	0.0070	1.44	0.302
W003MS07TI	50.0	Epoxy	0.0170	2.76	0.343
W003MS08TI	60.0	Epoxy	0.0280	2.71	0.412

Shaded areas indicate TCLP values that fail the treatment standard for the indicated metal.

$\leq$ Value is at or below the Instrument Detection Limit (IDL).

Table 3. Treatability study results for INEEL 426, *TAN TURCO Decon. Waste* (Treatment Standard: UTS).

Monolith Code	Waste Loading, wt%	Binder	Cr	η
426 Raw Waste [Total Metals, mg/kg]	(100)	none	4500	----
426.S.HC1	15.9	PC	20.35	-1.728
426.S.HC2	9.6	PC	6.375	-0.260
426.S.HC3	16.4	PC	14.24	-1.193
426.S.HC4	9.2	PC	4.872	-0.169
426.S.HCA1	14.0	PC	0.05	0.136
426.S.HCA2	8.4	PC	0.002	0.083
426.S.HCA3	14.5	PC	0.001	0.145
426.S.HCA4	8.8	PC	≤ 0.001	0.088
426.S.HCA5	14.3	PC	≤ 0.001	0.143
426.S.HCA6	13.3	PC	0.036	0.129

Shaded areas indicate TCLP values that fail the treatment standard for the indicated metal.
 $\leq$ Value is at or below the Instrument Detection Limit (IDL).

Table 4: Treatment standards in units of mg/L TCLP (8,9).

Standard:	Sb	As	Ba	Cd	Cr	Pb	Hg	Se	Ag
RCRA	NA	5.0	100	1.0	5.0	5.0	0.2	5.7	5.0
UTS*	2.1	5.0	7.6	0.19	0.86	0.37	0.025	0.16	0.30

* for non-wastewaters

NA Not Applicable

Fig. 1 : Effectiveness factor plots for INEEL mixed waste 147A treated with PC, comparing values obtained under RCRA vs UTS. The reference line represents theoretical maximum η values where $\eta = X_{Waste}$.

Fig. 2 : Effectiveness factor plots for INEEL mixed waste 147A, comparing treatments done with PC and PBC. The reference line represents theoretical maximum η values where $\eta = X_{Waste}$. Treatment standard is UTS.

Fig. 3 : Effectiveness factor plots for NAVY mixed waste MI-W003, comparing treatments done with epoxy and PC. The reference line represents theoretical maximum η values where $\eta = X_{Waste}$.

Fig. 4: Effectiveness factor plot for INEEL mixed waste 426 treated with PC, where the beneficial effect of additives is shown. The reference line is closely approached by η values.

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