

The Applicant's CD 2.30 raises ever more doubts regarding the competency and credibility of the Applicant's evidence in support of its application. In CD 2.24 staff has clearly stated concerns and identified errors in the Applicant's calculation. In Applicant's response (CD 2.30), Applicant has not demonstrated sufficient technical competency to recognize the seriousness of the errors which were identified by staff. Instead, Applicant defends its error regarding inconsistency of parameter values in engineering calculations and its equating of two heat transfer coefficients. Even more disturbing, Applicant makes several additional fundamental errors in CD 2.30 which will now be presented in detail.

*1. Applicant's Response to Inconsistency in Mass Flows*

In response to the question regarding the total mass flow of gasses, Applicant stated that:

The flame residence time calculation is a simultaneous mass transfer/heat transfer problem. *It is designed to answer the question, "what mass flow would result from the stoichiometric combustion of typical hazardous waste fuel considering heat loss to the environment?"* (Emphasis added.)

*Id.* at 5.

The first part of the emphasized sentence poses the question "what mass flow would result from the stoichiometric combustion of typical hazardous waste fuel?" Applicant, has previously calculated the stoichiometric combustion mass flow as 539,353 kg/hr. CD .97 at Attachment 1 to Appendix I.

The second part, “considering heat loss to the environment,” implies that stoichiometric mass flow will not be the calculated value of 539,353 kg/hr, but rather a function of heat loss.

The chemical laws of combining weights (discussed in the Applicant’s reference Peters on pgs. 29-30) requires that the mass flow for stoichiometric combustion of a typical hazardous waste fuel be defined by the molecules that make up the fuel’s composition and the molecules from the products of the combustion reaction. For Applicant to now state that the stoichiometric combustion mass is a function of heat losses is contra to this fundamental law.

Applicant continues:

This mass flow is, as pointed out by the HWFB Staff, approximately three times larger than the mass flow associated with the combustion air.

CD 2.30 at 5.

“This mass flow” refers to the stoichiometric mass flow of the preceding sentence, quoted above.

“Combustion air” refers to the mass flow reported in Attachment 1 to Appendix I of CD .97.

In effect Applicant makes the argument that stoichiometric mass flow is approximately three times stoichiometric mass flow. A glaring inconsistency.

This response of the Applicant to staffs concerns is very disturbing because Applicant attempts to deny the necessity for consistency of mass flows in engineering calculations and then compounds the severity of the error by statements in violation of the chemical laws of combining

weights. Thus instead of resolving concerns, CD 2.30 greatly increases doubts regarding **the** competency and credibility of the Applicant's evidence in support of its application.

## *2. Applicant's Response to Questions Regarding Flame Temperature*

First, Applicant ignores and misrepresents data of its cited reference Ndubizu.

Applicant ignores data in Ndubizu for gasoline and kerosene fires which should be comparable in combustion properties to Applicant's typical hazardous waste fuel. In particular, Applicant ignored the data of Table 4 of Ndubizu where flame temperature decreased as pan size increased, to values as low as 1135 °K.

Applicant misrepresents the data of Ndubizu's Tables 1 and 3 in the following statement:

- . The primary differences between the flame temperatures cited in this document and those calculated by Ndubizu et al. are associated with heats of combustion. Methanol produces a flame temperature of approximately 1500 °K as modeled by Ndubizu et al. and has an **enthalpy** of combustion of 174 kcal/mol. Xylene and isopropyl benzene, the hypothetical fuel used in this model, have enthalpies of combustion of 1090 and 1256 kcal/mol respectively, reflecting bond energy stored in the aromatic system. This additional energy release would be sufficient to account for the 600 °K difference.

CD 2.30 at 6.

In Table 1 of Ndubizu, it may be observed that the heat of combustion of gasoline, kerosene, and methanol are respectively  $4.39 \times 10^7$ ,  $4.3 \times 10^7$ , and  $2.23 \times 10^7$  W-sec/kg. With a conversion of Applicant's enthalpies of combustion of xylene and isopropyl benzene to the same mass based units (respectively about  $4.29 \times 10^7$  and  $4.36 \times 10^7$  W-sec/kg) it can be observed that they are approximately the same as the heat of combustion of gasoline and kerosene and only twice that of methanol.

Also, at Table 3, Ndubizu predicted and measured flame temperatures for gasoline, kerosene, and methanol fires are reported. The flame temperatures of methanol were highest at 1491 and 1504 °K, gasoline next at temperatures of 1299 and 1351 °K, and kerosene least with temperatures of 1263 and 1318 °K.

The data of Tables 1 and 3 of Ndubizu directly contradict Applicant's statements in CD 2.30.

It is very disturbing that Applicant would ignore and misrepresent data and statements in Applicant's cited reference when the applicant knows from staffs statements in CD 2.24 that staff have studied Applicant's reference Ndubizu. These actions of Applicant cause grave doubts regarding the competency and credibility of Applicant's evidence in support of its application.

Secondly, Applicant provides unsatisfactory answers for its actions regarding the inconsistency in the flame temperature in its calculations.

As noted *supra*, Applicant did not use a consistent estimate for flame temperature in its DRE calculation of hazardous waste fuel constituents. Applicant explains that a conservative default flame temperature estimate of 1000 °K was used in the Arrhenius equation calculation; a decision made when a review of the literature suggested that the temperature estimate of 2108 °K would only occur under ideal conditions. *Id.* at 7. Applicant further states that the 1000 °K temperature was inadvertently omitted from the footnotes on Table I. 1-1. *Id.*

If Applicant decided, after a fair and objective analysis of the fire risk scenario, that the flame temperature of 2108 °K was too high for a reasonable estimate of pool conditions, then one would expect Applicant to raise this issue as a carefully developed discussion, rather than an omitted footnote. Following such a discussion, if good engineering practice were followed, Applicant would recalculate flame height and mass flow at the temperature of 1000 °K. In fact, the question to Applicant is why present the flame temperature estimate of 2108 °K, if Applicant had decided that 1000 °K was a more appropriate temperature?

But Applicant did not discuss a possible flame temperature of 1000 °K. Applicant did not recalculate flame height and mass flow using a flame temperature estimate of 1000 °K. Applicant did not remove its flame temperature estimate calculation for 2108 °K from the risk scenario presented to the Board.

3. *Applicant's Response to Questions Regarding the Difference Between the Burn Rate and the Evaporation Rate*

Applicant also responds to the Board staff request for an explanation of why Applicant's estimation of the evaporation rate is about 1/40th the burn rate, and in particular, staff's question of whether the evaporation rate should not exceed the burn rate.

Applicant "knows of no *a priori* reason why the burn rate should not be greater than the evaporation rate." *Id.* at 8.

Once again, Applicant contradicts its reference Nduvizu, where at 234 and 235 it is shown that *evaporation rate be equal to or greater than the burn rate, as follows:*

Fuel is assumed to evaporate from the surface at the liquid boiling point,  $T_b$ , while the bulk of the liquid remains at  $T_b$ . Hence the fuel evaporation rate is:<sup>24</sup>

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<sup>24</sup>The terms in the Nduvizu et al. equations are defined as follows:

$T_b$	=	temperature of fuel in °K
$T_s$	=	temperature of fuel surface in °K
$m_v$	=	fuel evaporation rate in kg/sec
$A_s$	=	area of the fuel surface in m <sup>2</sup>
$h$	=	convective heat transfer coefficient in W/m <sup>2</sup> *°K
$T_f$	=	temperature of the flame in °K
$q_{r,surf}$	=	radiant heat transfer at the fuel surface in W
$H_v$	=	latent heat of vaporization of the fuel in W-sec/kg
$C_{fuel}$	=	specific heat of fuel in W-sec/kg*°K
$q_{gen}$	=	heat generated in the fire in W
$b$	=	efficiency of combustion
$H_c$	=	heat of combustion of the fuel in W-sec/kg

$$m_v = \frac{[A_s h_s (T_f - T_a) + q_{rs,net}]}{H_v + C_{fuel}(T_s - T_b)}$$

and at 235:

$$q_{gen.} = b m_v H_c$$

In generalized terms, the first equation states that the rate of fuel evaporation,  $m_v$ , is equal to the convection heat,  $A_s h_s (T_f - T_a)$ , plus the radiant heat,  $q_{rs,net}$ , which are transferred from the flame to the pool, divided by the sum of the heat required to raise the fuel to the boiling point,  $C_{fuel}(T_s - T_b)$ , plus the heat required to vaporize the fuel,  $H_v$ . The second equation states that the total heat of combustion is equal to the combustion efficiency, "b", times the rate of evaporation of fuel,  $m_v$ , times the heat content of the fuel,  $H_c$ . The second equation shows that the actual burn rate is some fraction of the evaporation rate, *i.e.* a portion of the fuel which is evaporated burns in the fire and a portion is carried from the flame as a component of the plume gasses.

Applicant's own equation for burn rate has a form similar to the equation used by Ndubizu. The Applicant's equation<sup>25</sup>, at CD .97 page I-2, is:

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<sup>25</sup>The terms of Applicant's burn rate equation are defined as follows:

- $m_c$  = burning rate in kg/sec
- $H_c$  = heat of combustion in J/kg
- $C_p$  = heat capacity of chemical in J/kg-°K

$$m_c = \frac{0.001H_c\pi r^2}{C_p(T_B - T_A) + H_{vap}}$$

The denominator of this equation, which is the same as in Ndubizu's equation, is the heat required to raise the fuel to the boiling point, plus the heat required to vaporize the fuel. The numerator is a fraction of the total heat of combustion and is an estimate of the heat transferred from the flame to the surface of the fuel. Thus both Applicant's and Ndubizu's equations are a ratio of heat flow to the surface of the fuel, to the heat required to boil and vaporize the fuel.

Applicant attempts to deny that evaporation must be equal to or exceed the burn rate with the following statement.

It is conventional wisdom in fire fighting practice to allow many flammable liquid fires to burn themselves out in order to limit downwind exposure to volatilized organic chemicals. The greater burn rate reflects this phenomenon whereby the evaporating chemicals are being rapidly consumed by the fire.

CD 2.30 at 8

While it may be the conventional wisdom of fire fighting practice to allow a flammable liquid fire to burn, this does not negate the fact that before the liquid burns it must evaporate to form vapors which can then mix with air prior to combustion. If no volatilized chemicals are carried

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$T_B$	=	atmospheric boiling point in °K
$T^A$	=	ambient temperature in °K
$r$	=	pool fire radius in m
$H_{vap}$	=	heat of vaporization in J/kg