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1	1	Cog.Eng. S.D. Estey	S.D. Estey	6/2/97	R2-11	1	1	S.A. Barker	S.A. Barker	6/2/97	R2-11
1	1	Cog. Mgr. N.W. Kirch	N.W. Kirch	6/2/97	R2-11	1	1	J.G. Kristofzski	J.G. Kristofzski	6/3/97	R2-12
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Calculation Note: Project W-320 Primary Ventilation Air Flow Requirements for Mitigation of Steady State Flammable Gas Concentrations in the Headspaces of Tanks 241-C-106 and 241-AY-102

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Abstract: This Calculation Note analyzes the concentration of flammable gases in the headspaces of tanks 241-C-106 and 241-AY-102. Using measured and/or estimated hydrogen generation rates, the required minimum air flow rates and response times to a loss of ventilation condition are calculated. The conditions analyzed include: 1) tank 241-C-106 before sluicing, 2) tank 241-AY-102 before sluicing, and 3) tank 241-AY-102 after sluicing, assuming all of the waste contained in tank 241-C-106 has been transferred to it.

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Title:

Calculation Note: Project W-320 Primary Ventilation Air Flow Requirements for Mitigation of Steady State Flammable Gas Concentrations in the Headspaces of Tanks 241-C-106 and 241-AY-102.

Purpose:

This calculation note analyzes headspace concentrations of hydrogen dependent upon assumed ventilation flow rates provided for tanks 241-C-106 and 241-AY-102. The analyses are based on measured or estimated steady state hydrogen release rates. Tank 241-C-106 is analyzed prior to sluicing; tank 241-AY-102 is analyzed both prior to and after completion of sluicing. Specific analyses, using both best estimated and bounding hydrogen generation rates, include:

1) The minimum primary ventilation flow rates required in the tanks to ensure that the steady state hydrogen concentration in the respective tank headspace does not exceed 25% and 100% of the LFL.

2) The headspace hydrogen concentration as a function of time as well as the time required to reach 25% and 100% of LFL (i.e., the required response time) upon complete loss of active ventilation, starting from the steady state hydrogen concentration based on a 200 CFM minimum flow rate in tank 241-C-106 and a 100 CFM minimum flow rate in tank 241-AY-102.

3) The headspace hydrogen concentration as a function of time following partial loss of active ventilation (i.e., step changes to 160, 120, 80, and 40 CFM ventilation flow rates) in tank 241-C-106, starting from a 200 CFM flow rate and the corresponding steady state hydrogen concentration based on the 200 CFM flow rate.

4) The headspace hydrogen concentration as a function of time following partial loss of active ventilation (i.e., step changes to 80, 60, 40, and 20 CFM ventilation flow rates) in tank 241-AY-102, starting from a 100 CFM flow rate and the corresponding steady state hydrogen concentration based on the 100 CFM flow rate.

Methodology:

The calculations utilize referenced values of steady-state hydrogen release rates in both tanks. The calculations are performed and documented using Mathcad V6.0.

Once the total hydrogen generation rate is known for each of the tanks (gr), the required ventilation flow rate (vr) to control the gas concentration in the headspace equivalent to a specified steady state hydrogen concentration is the quantity (vr) such that the expression 100(gr/(gr+vr)) equals the desired headspace hydrogen concentration measured in volume percent.

The transient response of hydrogen concentration in the tank headspace to a step change in ventilation flow rate is also calculated using the determined hydrogen generation rate for each tank, an initial tank ventilation rate, the tank headspace volume, and the initial tank headspace hydrogen concentration.

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Assumptions:

- The hydrogen generation rates in the tanks are 20 SCFD best estimate and 45 SCFD bounding value for tank 241-C-106 before sluicing; 51 SCFD best estimate and 60 SCFD bounding value for tank 241-AY-102 before sluicing; 71 SCFD best estimate and 105 SCFD bounding value for tank 241-AY-102 after sluicing.

- The models for the headspace hydrogen concentrations are mathematical constructs needing no assumptions other than complete, instantaneous mixing of hydrogen in the tank headspace.

- The assumed minimum active ventilation flow rate is 200 CFM in tank 241-C-106, 100 CFM in tank 241-AY-102.

- The headspace volume of tank 241-C-106 is assumed as 95,000 ft^3 before sluicing. The headspace volume of tank 241-AY-102 is assumed as 33,000 ft^3 both before and after sluicing. Both values are referenced.

- When active ventilation is occurring in a tank, the contribution of passive ventilation to the total ventilation rate is assumed to be negligible.

- The passive ventilation rate in the tanks is assumed as a referenced value of 0.45 volume percent turnover per day.

- The assumed composition of gases generated in the tanks cause the LFL to occur at 2.5 volume % hydrogen, and 25% LFL to occur at 0.625 volume % hydrogen.

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Input Data:

cases evaluated:

$n := 1..6$

n	
1	n = 1 corresponds to tank C-106 pre-sluicing best estimate
2	n = 2 corresponds to tank C-106 pre-sluicing bounding value
3	n = 3 corresponds to tank AY-102 pre-sluicing best estimate
4	n = 4 corresponds to tank AY-102 pre-sluicing bounding value
5	n = 5 corresponds to tank AY-102 post-sluicing best estimate
6	n = 6 corresponds to tank AY-102 post-sluicing bounding value

hydrogen generation rate:

n	$gr_n :=$	Reference:
1	$20 \cdot ft^3 \cdot day^{-1}$	1 (Pasamehmetoglu 1997)
2	$45 \cdot ft^3 \cdot day^{-1}$	2 (Pasamehmetoglu 1997)
3	$51 \cdot ft^3 \cdot day^{-1}$	3 (LANL estimate from SHMS data)
4	$60 \cdot ft^3 \cdot day^{-1}$	4 (LANL estimate from SHMS data)
5	$71 \cdot ft^3 \cdot day^{-1}$	5 sum of 1 & 3
6	$105 \cdot ft^3 \cdot day^{-1}$	6 sum of 2 & 4

tank ventilation rates:

n	$vr_n :=$	Reference:
1	$200 \cdot ft^3 \cdot min^{-1}$	1 (assumption)
2	$200 \cdot ft^3 \cdot min^{-1}$	2 (assumption)
3	$100 \cdot ft^3 \cdot min^{-1}$	3 (Estey 1997)
4	$100 \cdot ft^3 \cdot min^{-1}$	4 (Estey 1997)
5	$100 \cdot ft^3 \cdot min^{-1}$	5 (Estey 1997)
6	$100 \cdot ft^3 \cdot min^{-1}$	6 (Estey 1997)

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tank headspace volumes:

n	$vol_n :=$
1	$95000 \cdot ft^3$
2	$95000 \cdot ft^3$
3	$33000 \cdot ft^3$
4	$33000 \cdot ft^3$
5	$33000 \cdot ft^3$
6	$33000 \cdot ft^3$

Reference:
1 (Pasamehmetoglu 1997)
2 (Pasamehmetoglu 1997)
3 (Estey 1997)
4 (Estey 1997)
5 (Estey 1997)
6 (Estey 1997)

Calculations

Derivation of ventilation equations

$gr = tankH2generationrate$ $volH2 = H2volume$ $\%H2 = 100 \cdot \frac{volH2}{vol}$

$vr = tankventilationrate$ $volH2_i = initialH2volume$

$vol = tankheadspacevolume$ $volH2_t = currentH2volume$

The rate of change of hydrogen volume in a tank headspace equals the volumetric hydrogen generation rate [gr] minus the volumetric hydrogen loss rate [volumetric flow rate exiting the tank (i.e., gr + vr) times the volume percent hydrogen in exhaust air (i.e., volH2/vol)].

$$\frac{d(volH2)}{dt} = (H2generationrate - H2lossrate) = \left[gr - (gr + vr) \cdot \frac{\%H2}{100}\right] = \left[gr - (gr + vr) \cdot \frac{volH2}{vol}\right]$$

$$\frac{d(volH2)}{dt} = \left[gr - (gr + vr) \cdot \frac{volH2}{vol}\right]$$

Separating the variables,

$$dt = \frac{d(volH2)}{\left[gr - (gr + vr) \cdot \frac{volH2}{vol}\right]} = \frac{d(volH2)}{\left[gr - \left(\frac{gr + vr}{vol}\right) \cdot volH2\right]}$$

Factoring the equation by the differential of the volH2 term,

$$-\left(\frac{gr + vr}{vol}\right) \cdot dt = \frac{-\left(\frac{gr + vr}{vol}\right) \cdot d(volH2)}{\left[gr - \left(\frac{gr + vr}{vol}\right) \cdot volH2\right]}$$

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Integrating the equation and evaluating between the limits of time = 0 to time = t, and volH2 = volH2i to volH2 = volH2t,

$$\int_0^t -\left(\frac{gr+vr}{vol}\right) dt = \int_{volH2_i}^{volH2_t} \frac{-\left(\frac{gr+vr}{vol}\right)}{\left[gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2\right]} d(volH2)$$

$$-\left(\frac{gr+vr}{vol}\right)\cdot t = \ln\left[gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_t\right] - \ln\left[gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_i\right]$$

Solving for time (t) as a function of the current volume of hydrogen contained in the tank headspace, (volH2t),

$$t = -\left(\frac{vol}{gr+vr}\right)\cdot\left[\ln\left[gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_t\right] - \ln\left[gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_i\right]\right]$$

$$t = -\left(\frac{vol}{gr+vr}\right)\cdot\left[\ln\left[\frac{gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_t}{gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_i}\right]\right]$$

Solving for the current concentration of hydrogen contained in the tank headspace, (volH2t/vol), as a function of time t,

$$\ln\left[gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_t\right] = \ln\left[gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_i\right] - \left(\frac{gr+vr}{vol}\right)\cdot t$$

$$\left[gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_t\right] = \left[gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_i\right]\cdot\exp\left[-\left[\left(\frac{gr+vr}{vol}\right)\cdot t\right]\right]$$

$$\left(\frac{gr+vr}{vol}\right)\cdot volH2_t = gr-\left[gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_i\right]\cdot\exp\left[-\left[\left(\frac{gr+vr}{vol}\right)\cdot t\right]\right]$$

$$(gr+vr)\cdot\frac{volH2_t}{vol} = gr-\left[gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_i\right]\cdot\exp\left[-\left[\left(\frac{gr+vr}{vol}\right)\cdot t\right]\right]$$

$$\frac{volH2_t}{vol} = \frac{\%H2_t}{100} = \frac{gr-\left[gr-\left(\frac{gr+vr}{vol}\right)\cdot volH2_i\right]\cdot\exp\left[-\left[\left(\frac{gr+vr}{vol}\right)\cdot t\right]\right]}{(gr+vr)}$$

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At steady state (equivalent to t = ∞), the exponential term drops out and,

$$\frac{volH2_t}{vol} = \frac{\%H2_t}{100} = \left(\frac{gr}{gr + vr}\right)$$

Required tank ventilation rate to maintain steady state hydrogen concentration:

$$vr = 100 \cdot \left(\frac{gr}{\%H2_t}\right) - gr$$

Required ventilation rate (m³ per second; CFM) to keep tank headspace concentration below 100% LFL (equivalent to 2.5% hydrogen):

$$vrlfl_n := 100 \cdot \left(\frac{gr_n}{2.5}\right) - gr_n$$

n	$vrlfl_n$ $\left(\frac{m^3}{sec}\right)$	$vrlfl_n$ $\left(\frac{ft^3}{min}\right)$
1	$2.556 \cdot 10^{-4}$	0.542
2	$5.752 \cdot 10^{-4}$	1.219
3	$6.519 \cdot 10^{-4}$	1.381
4	$7.669 \cdot 10^{-4}$	1.625
5	$9.075 \cdot 10^{-4}$	1.923
6	$1.342 \cdot 10^{-3}$	2.844

Required ventilation rate (m³ per second; CFM) to keep tank headspace concentration below 25% LFL (equivalent to 0.625% hydrogen):

$$vr25_n := 100 \cdot \left(\frac{gr_n}{0.625}\right) - gr_n$$

n	$vr25_n$ $\left(\frac{m^3}{sec}\right)$	$vr25_n$ $\left(\frac{ft^3}{min}\right)$
1	$1.042 \cdot 10^{-3}$	2.208
2	$2.345 \cdot 10^{-3}$	4.969
3	$2.658 \cdot 10^{-3}$	5.631
4	$3.127 \cdot 10^{-3}$	6.625
5	$3.7 \cdot 10^{-3}$	7.84
6	$5.472 \cdot 10^{-3}$	11.594

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Determine the steady state hydrogen concentration (% hydrogen) in the tank headspace at the minimum per tank W-030 ventilation flow rate of 200 CFM for tank 241-C-106 and 100 CFM for tank 241-AY-102:

$$\%H_{2i_n} := 100 \cdot \left(\frac{gr_n}{gr_n + vr_n} \right)$$

n	$\%H_{2i_n}$
1	0.0069
2	0.0156
3	0.0354
4	0.0416
5	0.0493
6	0.0729

Natural ventilation flow rate in tanks 241-C-106 and 241-AY-102 (m^3 per second; CFM):

$$vr_{passive_n} := 0.0045 \cdot \frac{vol_n}{day}$$

Reference: (Crippen 1993)

n	$\frac{vr_{passive_n}}{\left(\frac{m^3}{sec}\right)}$	$\frac{vr_{passive_n}}{\left(\frac{ft^3}{min}\right)}$
1	$1.401 \cdot 10^{-4}$	0.297
2	$1.401 \cdot 10^{-4}$	0.297
3	$4.867 \cdot 10^{-5}$	0.103
4	$4.867 \cdot 10^{-5}$	0.103
5	$4.867 \cdot 10^{-5}$	0.103
6	$4.867 \cdot 10^{-5}$	0.103
	$4.867 \cdot 10^{-5}$	

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Determine the time to exceed 25% LFL (equivalent to 0.625% hydrogen) upon complete loss of active ventilation (seconds; days):

$$t_{25_n} := -\left(\frac{vol_n}{gr_n + vr_{passive_n}}\right)\cdot \ln\left[\frac{gr_n - \left(\frac{gr_n + vr_{passive_n}}{vol_n}\right)\cdot\frac{0.625\cdot vol_n}{100}}{gr_n - \left(\frac{gr_n + vr_{passive_n}}{vol_n}\right)\cdot\frac{\%H_{2i_n}\cdot vol_n}{100}}\right]$$

n	$\frac{t_{25_n}}{(sec)}$	$\frac{t_{25_n}}{(day)}$
1	$2.735\cdot10^6$	31.65
2	$1.151\cdot10^6$	13.317
3	$3.339\cdot10^5$	3.865
4	$2.805\cdot10^5$	3.246
5	$2.336\cdot10^5$	2.704
6	$1.512\cdot10^5$	1.75

Determine the time to exceed 100% LFL (equivalent to 2.5% hydrogen) upon complete loss of active ventilation (seconds; days):

$$t_{100_n} := -\left(\frac{vol_n}{gr_n + vr_{passive_n}}\right)\cdot \ln\left[\frac{gr_n - \left(\frac{gr_n + vr_{passive_n}}{vol_n}\right)\cdot\frac{2.5\cdot vol_n}{100}}{gr_n - \left(\frac{gr_n + vr_{passive_n}}{vol_n}\right)\cdot\frac{\%H_{2i_n}\cdot vol_n}{100}}\right]$$

n	$\frac{t_{100_n}}{(sec)}$	$\frac{t_{100_n}}{(day)}$
1	$1.5\cdot10^7$	173.655
2	$5.261\cdot10^6$	60.89
3	$1.451\cdot10^6$	16.794
4	$1.223\cdot10^6$	14.155
5	$1.025\cdot10^6$	11.864
6	$6.804\cdot10^5$	7.875

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Resulting hydrogen concentration (volume percent) in tank headspace upon total loss of active ventilation as a function of time (days):

$tnarrow := 0..20$

$$\%H2_{n,tnarrow} := 100 \cdot \frac{gr_n - \left[gr_n - \left(\frac{gr_n + vr\,passive_n}{vol_n}\right) \cdot \frac{\%H2i_n \cdot vol_n}{100}\right] \cdot \exp\left[-\left(\frac{gr_n + vr\,passive_n}{vol_n} \cdot tnarrow \cdot day\right)\right]}{\left(gr_n + vr\,passive_n\right)}$$

$twide := 0, 20..1000$

$$\%H2_{n,twide} := 100 \cdot \frac{gr_n - \left[gr_n - \left(\frac{gr_n + vr\,passive_n}{vol_n}\right) \cdot \frac{\%H2i_n \cdot vol_n}{100}\right] \cdot \exp\left[-\left(\frac{gr_n + vr\,passive_n}{vol_n} \cdot twide \cdot day\right)\right]}{\left(gr_n + vr\,passive_n\right)}$$

Determine the response of hydrogen concentration (volume percent) in tank headspace upon partial loss of active ventilation as a function of time (hours) and the reduced ventilation flow rate:

$thours := 0, 6..240$

$p := 1..5$

$vr_p := p \cdot 20 \cdot ft^3 \cdot min^{-1}$

$$C106pre\%H2_{p,thours} := 100 \cdot \frac{gr_2 - \left[gr_2 - \left(\frac{gr_1 + 2 \cdot vr_p}{vol_2}\right) \cdot \frac{\%H2i_2 \cdot vol_2}{100}\right] \cdot \exp\left[-\left[\left(\frac{gr_2 + 2 \cdot vr_p}{vol_2}\right) \cdot thours \cdot hr\right]\right]}{\left(gr_2 + 2 \cdot vr_p\right)}$$

$$AY102pre\%H2_{p,thours} := 100 \cdot \frac{gr_4 - \left[gr_4 - \left(\frac{gr_4 + vr_p}{vol_4}\right) \cdot \frac{\%H2i_4 \cdot vol_4}{100}\right] \cdot \exp\left[-\left[\left(\frac{gr_4 + vr_p}{vol_4}\right) \cdot thours \cdot hr\right]\right]}{\left(gr_4 + vr_p\right)}$$

$$AY102post\%H2_{p,thours} := 100 \cdot \frac{gr_6 - \left[gr_6 - \left(\frac{gr_6 + vr_p}{vol_6}\right) \cdot \frac{\%H2i_6 \cdot vol_6}{100}\right] \cdot \exp\left[-\left[\left(\frac{gr_6 + vr_p}{vol_6}\right) \cdot thours \cdot hr\right]\right]}{\left(gr_6 + vr_p\right)}$$

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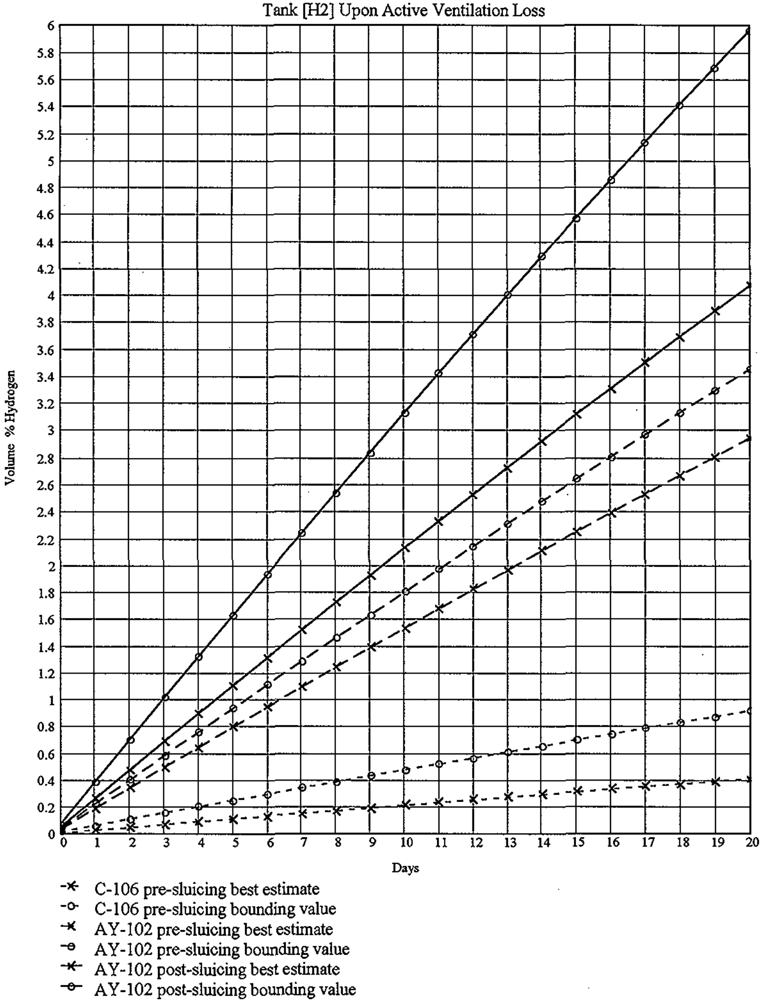

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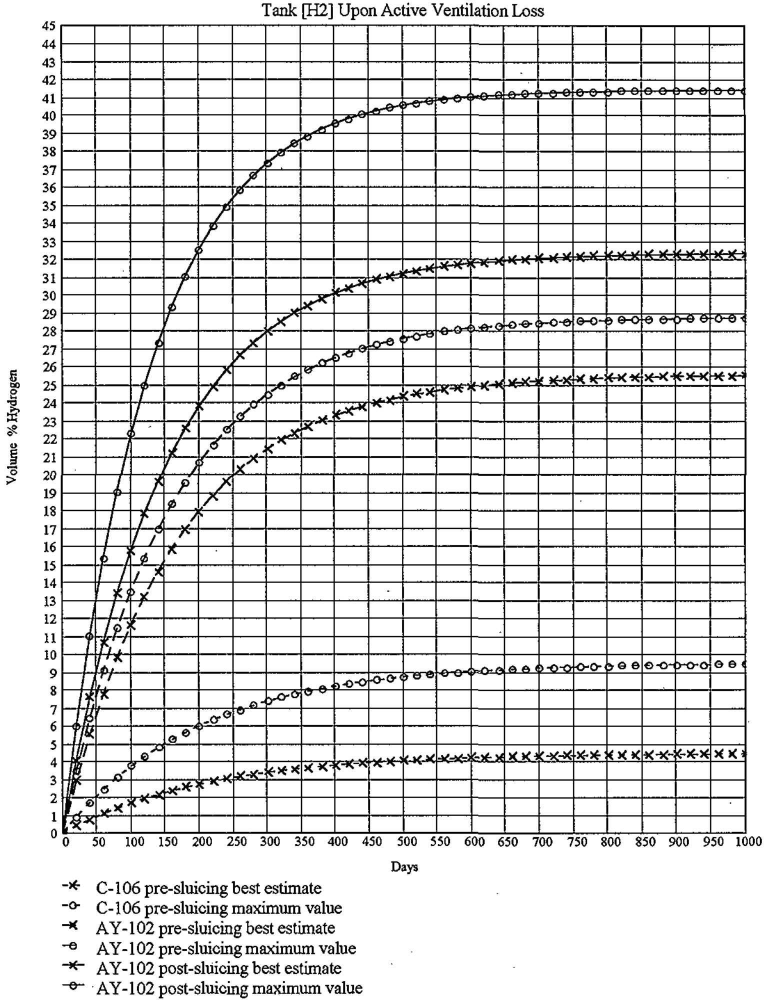

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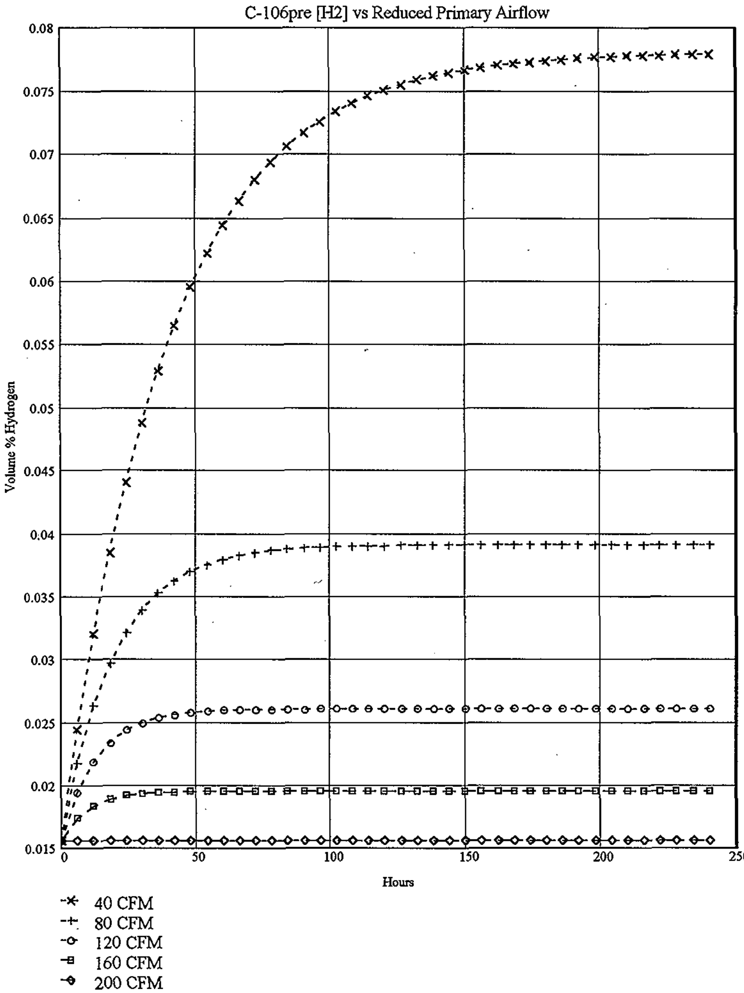

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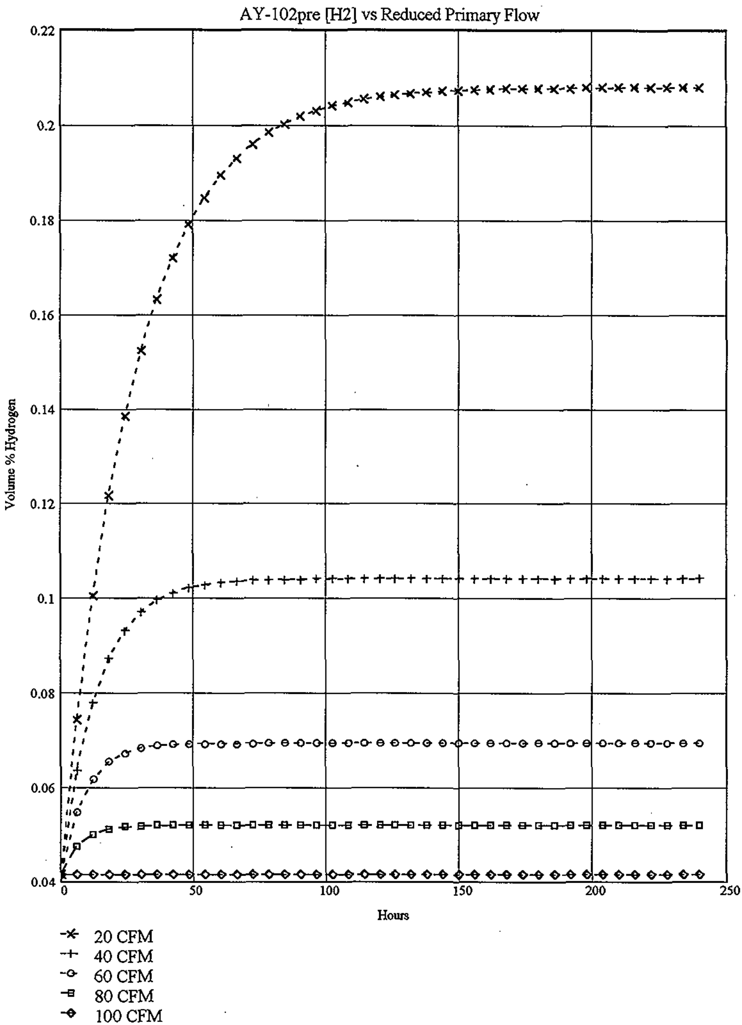

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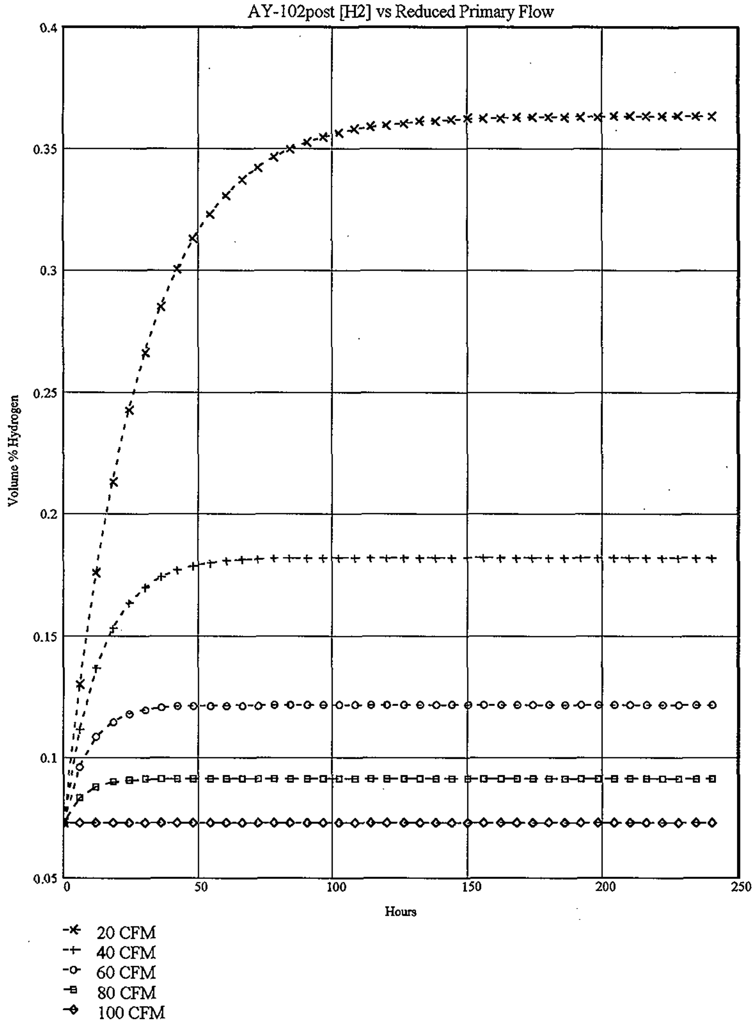

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Results:

1) The minimum primary ventilation flow rates required to ensure that the tank headspaces do not reach 25% and 100% of the LFL are shown on page 6.

2) Following complete loss of forced ventilation, the headspace hydrogen concentration as a function of time, and the times to reach 25% and 100% of the LFL , are shown on pages 10 & 11, and page 8, respectively.

3 & 4) Headspace hydrogen concentrations following various partial losses of forced ventilation are shown as a function of time, using the bounding hydrogen generation rates, on pages 12 and 13 for tank 241-C-106, and on page 14 for tank 241-AY-102.

The results show that the hydrogen generation rates in the tanks utilized by Project W-320 are low enough that only a very small ventilation rate is needed to ensure that a steady state release of gas with the assumed composition will not result in a uniform tank headspace fuel loading exceed 25% of the LFL. A ventilation flow rate of 100 CFM is calculated to be roughly an order of magnitude greater than the flow rate required to satisfy the <25% LFL criteria for these tanks at any of the analyzed conditions. The flammable limits would become a concern in the tank headspaces following complete loss of forced ventilation. In all cases, the requirement to remain < 25% LFL cannot be met by passive ventilation alone. As a rough order of magnitude estimate, using bounding hydrogen generation rates, the < 25% LFL limit would be reached at 1.75 days for tank 241-AY-102 in its limiting waste condition, and at 13.3 days for tank 241-C-106 in its initial condition. If an extended loss of forced ventilation were long enough, the tank headspaces would eventually exceed the LFL in all the analyzed conditions.

Conclusions:

A 100 CFM primary ventilation flow rate is sufficient to prevent the formation of a uniformly flammable tank headspace composition in the tanks utilized by Project W-320, even if all the waste resides in tank 241-AY-102. However, using bounding hydrogen generation rates, if forced ventilation were completely lost on these tanks, the 0.625 percent hydrogen control limit is predicted to occur at 1.75 days for tank 241-AY-102 in its limiting condition (i.e., following complete retrieval of tank 241-C-106 wastes), and at 13.3 days for tank 241-C-106 in its initial condition.

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Crippen, M.D., 1993, "Barometric Pressure Variations," WHC-EP-0651, Westinghouse Hanford Company, Richland, Washington.

CHECKLIST FOR PEER REVIEW

Document Reviewed: **HNF-SD-WM-CN-114, Rev. 0**

Scope of Review:

Yes	No	NA	
[ ]	[ ]	[✓]	* Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[✓]	[ ]	[ ]	Problem completely defined.
[ ]	[ ]	[✓]	Accident scenarios developed in a clear and logical manner.
[✓]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[✓]	[ ]	[ ]	Computer codes and data files documented.
[✓]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[✓]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[✓]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[✓]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[✓]	[ ]	[ ]	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[✓]	[ ]	[ ]	Software input correct and consistent with document reviewed.
[✓]	[ ]	[ ]	Software output consistent with input and with results reported in document reviewed.
[✓]	[ ]	[ ]	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[✓]	[ ]	[ ]	Safety margins consistent with good engineering practices.
[✓]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.
[ ]	[ ]	[✓]	Format consistent with appropriate NRC Regulatory Guide or other standards
[✓]		[ ]	Review calculations, comments, and/or notes are attached.
[✓]	[ ]	[ ]	**Document approved.**

S. A. Barker/ [signature] 6-2-97

Reviewer (Printed Name and Signature) Date

* Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

	B	C	D	E	F	G	H	I	J	K	L
2	Check of Calc Note: HNF-SD-WM-CN-114 Rev 0.										
3			1	2	3	4	5	6		Variable	Range
4	Tank		C-106	C-106	AY102 Before	AY102 Before	AY102-After	AY102-After	Formula	Name	Name
5			Best Est	Bounding	Best Est	Bounding	Best Est	Bounding			
6	Conversion factor - days to second	sec/day	86400							conv_day_sec	cvdaysec
7	Conversion factor - liters to meter^3	m^3/L	0.001							conv_L_m3	cvlm3
8	Conversion factor - feet to meter	m/ft	0.3048							conv_ft_m	cvftm
9	Conversion factor - gallons to meter^3	m^3/gal	0.00379							conv_gal_m3	cvgalm3
10	Conversion factor - Btu to joules	joules/btu	1,055.06							conv_btu_joules	cvbtujoules
11	Conversion factor - m^3/sec to ft^3/min	(ft^3/min)/(m^3/sec)	2,118.88							conv_cms_cfm	cvcmscfm
12	Volume headspace	ft^3	95,000	95,000	33,000	33,000	33,000	33,000	Given	vol	
13	Hydorgen generation rate total	ft^3/day	20	45	51	60	71	105	Given	grE	
14	Hydorgen generation rate total	m^3/sec	6.55E-06	1.47E-05	1.67E-05	1.97E-05	2.33E-05	3.44E-05	+ I13 * ($D$8^3) / $D$6	gr	
15	Ventilation Rate	ft^3/min	200	200	100	100	100	100	Given	vrE	
16	Ventilation Rate	m^3/sec	9.44E-02	9.44E-02	4.72E-02	4.72E-02	4.72E-02	4.72E-02	+ I15 * ($D$8^3) / 60	vr	
17	Vent Rate ==> H2 < 2.5% (100%LFL)	m^3/sec	2.556E-04	5.752E-04	6.519E-04	7.669E-04	9.075E-04	1.342E-03	100 * I14 / 2.5 - I14	vlfl	
18	Vent Rate ==> H2 < 2.5% (100%LFL)	ft^3/min	0.542	1.219	1.381	1.625	1.923	2.844	+ I17 * $A:$D$11..$A:$D$11	vlflE	
19	Vent Rate ==> H2 < .625 (25% LFL)	m^3/sec	1.042E-03	2.345E-03	2.658E-03	3.127E-03	3.700E-03	5.472E-03	100 * I14 / (2.5 / 4) - I14	vr	
20	Vent Rate ==> H2 < .625 (25% LFL)	ft^3/min	2.208	4.969	5.631	6.625	7.840	11.594	+ I19 * $D$11..$D$11	vrE	
21	Steady-state hydrogen concentration	%	0.0069	0.0156	0.0354	0.0416	0.0493	0.0729	+ I13 / (I13 + I15 * 24 * 60) * 100	%h_2i	
22	Natural Ventilation Flow Rate (No Convection)	volume/day	0.0045						Given	vr_passiveV	
23	Natural Ventilation Flow Rate (No Convection)	m^3/sec	1.401E-04	1.401E-04	4.867E-05	4.867E-05	4.867E-05	4.867E-05	+ $D$22 * I12 / $D$11 / 24 / 60	vr_passive	
24	Natural Ventilation Flow Rate (No Convection)	ft^3/min	0.297	0.297	0.103	0.103	0.103	0.103	+ $D$22 * I12 / 24 / 60	vr_passiveE	
25	Time to exceed 25% LFL, loss of ventilation	day	31.650	13.317	3.865	3.246	2.704	1.750	@IF(((I14 - (I14 + I23) * 0.625 / 100) / (I14 - (I14 + I23) * I21 / 100))<0,">1E6",(- I12 * $A:$D$8..$A:$D$8^3 / (I14 + I23) * (@LN((I14 - (I14 + I23) * 0.625 / 100) / (I14 - (I14 + I23) * I21 / 100)))) / 60 / 60 / 24)	t25	
26	Time to exceed 25% LFL, loss of ventilation	sec	2.735E+06	1.151E+06	3.339E+05	2.805E+05	2.336E+05	1.512E+05	+ I25 * $D$6		
27	Time to exceed 100% LFL, loss of ventilation	day	173.655	60.890	16.794	14.155	11.864	7.875	@IF(((I14 - (I14 + I23) * 2.5 / 100) / (I14 - (I14 + I23) * I21 / 100))<0,">1E6",(- I12 * $A:$D$8..$A:$D$8^3 / (I14 + I23) * (@LN((I14 - (I14 + I23) * 2.5 / 100) / (I14 - (I14 + I23) * I21 / 100)))) / 60 / 60 / 24)	t100	
28	Time to exceed 8% H, loss of ventilation	day	1.500E+07	5.261E+06	1.451E+06	1.223E+06	1.025E+06	6.804E+05	+ I27 * $D$6	t8	
29											
30	**H2 concentration - loss of vent**										
31	time=1 day	%	0.02791	0.06280	0.18927	0.22263	0.26339	0.38927	100 * ((I$13 - (I$13 - (I$13 + I$24 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$24 * 60 * 24) / I$12 * 1)) / (I$13 + I$24 * 60 * 24))	%H2_tnarrow	
32	time=2 day	%	0.04879	0.10974	0.34221	0.40247	0.47608	0.70325	100 * ((I$13 - (I$13 - (I$13 + I$24 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$24 * 60 * 24) / I$12 * 2)) / (I$13 + I$24 * 60 * 24))	%H2_tnarrow	
33	time=4 day	%	0.09024	0.20292	0.64533	0.75877	0.89725	1.32403	100 * ((I$13 - (I$13 - (I$13 + I$24 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$24 * 60 * 24) / I$12 * 4)) / (I$13 + I$24 * 60 * 24))	%H2_tnarrow	
34	time=6 day	%	0.13130	0.29517	0.94480	1.11059	1.31284	1.93534	100 * ((I$13 - (I$13 - (I$13 + I$24 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$24 * 60 * 24) / I$12 * 6)) / (I$13 + I$24 * 60 * 24))	%H2_tnarrow	

HNF-SD-WM-CN-114, Rev. 0

	B	C	D	E	F	G	H	I	J	K	L
2	Check of Calc Note: HNF-SD-WM-CN-114 Rev 0.										
3			1	2	3	4	5	6		Variable	Range
4	Tank		C-106	C-106	AY102 Before	AY102 Before	AY102-After	AY102-After	Formula	Name	Name
5			Best Est	Bounding	Best Est	Bounding	Best Est	Bounding			
35	time=8 day	%	0.17197	0.38652	1.24067	1.45799	1.72295	2.53734	100 * ((I$13 - (I$13 - (I$13 + I$24 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$24 * 60 * 24) / I$12 * 8)) / (I$13 + I$24 * 60 * 24))	%H2_tnarrow	
36	time=10 day	%	0.21227	0.47696	1.53299	1.80103	2.12763	3.13015	100 * ((I$13 - (I$13 - (I$13 + I$24 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$24 * 60 * 24) / I$12 * 10)) / (I$13 + I$24 * 60 * 24))	%H2_tnarrow	
37	time=15 day	%	0.31136	0.69917	2.24851	2.63991	3.11610	4.57295	100 * ((I$13 - (I$13 - (I$13 + I$24 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$24 * 60 * 24) / I$12 * 15)) / (I$13 + I$24 * 60 * 24))	%H2_twide	
38	time=20 day	%	0.40815	0.91592	2.94273	3.45270	4.07224	5.96138	100 * ((I$13 - (I$13 - (I$13 + I$24 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$24 * 60 * 24) / I$12 * 20)) / (I$13 + I$24 * 60 * 24))	%H2_twide	
39	time=100 day	%	1.68324	3.74161	11.61711	13.50058	15.73929	22.24096	100 * ((I$13 - (I$13 - (I$13 + I$24 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$24 * 60 * 24) / I$12 * 100)) / (I$13 + I$24 * 60 * 24))	%H2_twide	
40	time=1000 day	%	4.42911	9.45804	25.50344	28.72516	32.30451	41.40105	100 * ((I$13 - (I$13 - (I$13 + I$24 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$24 * 60 * 24) / I$12 * 1000)) / (I$13 + I$24 * 60 * 24))	%H2_twide	
41											
42	**H2 concentration - loss of ventilation**										
43	vent rate =	ft^3/min		40		20		20			
44	time = 6 hours	%		0.02441		0.07430		0.12997	100 * ((I$13 - (I$13 - (I$13 + I$43 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$43 * 60 * 24) / I$12 * 6 / 24)) / (I$13 + I$43 * 60 * 24))	%H2	
45	time = 30 hours	%		0.04882		0.15218		0.26610	100 * ((I$13 - (I$13 - (I$13 + I$43 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$43 * 60 * 24) / I$12 * 30 / 24)) / (I$13 + I$43 * 60 * 24))	%H2	
46	time = 90 hours	%		0.07165		0.20164		0.35238	100 * ((I$13 - (I$13 - (I$13 + I$43 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$43 * 60 * 24) / I$12 * 90 / 24)) / (I$13 + I$43 * 60 * 24))	%H2	
47	time = 120 hours	%		0.07506		0.20580		0.35962	100 * ((I$13 - (I$13 - (I$13 + I$43 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$43 * 60 * 24) / I$12 * 120 / 24)) / (I$13 + I$43 * 60 * 24))	%H2	
48	time = 240 hours	%		0.07792		0.20787		0.36321	100 * ((I$13 - (I$13 - (I$13 + I$43 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$43 * 60 * 24) / I$12 * 240 / 24)) / (I$13 + I$43 * 60 * 24))	%H2	
49											
50	vent rate =	ft^3/min		80		40		40			
51	time = 3 hours	%		0.02175		0.06374		0.11150	100 * ((I$13 - (I$13 - (I$13 + I$50 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$50 * 60 * 24) / I$12 * 6 / 24)) / (I$13 + I$50 * 60 * 24))	%H2	

HNF-SD-WM-CN-114, Rev.0

	B	C	D	E	F	G	H	I	J	K	L
2	Check of Calc Note: HNF-SD-WM-CN-114 Rev 0.										
3			1	2	3	4	5	6		Variable	Range
4	Tank		C-106	C-106	AY102 Before	AY102 Before	AY102-After	AY102-After	Formula	Name	Name
5			Best Est	Bounding	Best Est	Bounding	Best Est	Bounding			
52	time = 30 hours	%		0.03391		0.09703		0.16970	100 * ((I$13 - (I$13 - (I$13 + I$50 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$50 * 60 * 24) / I$12 * 30 / 24)) / (I$13 + I$50 * 60 * 24))	%H2	
53	time = 90 hours	%		0.03880		0.10397		0.18181	100 * ((I$13 - (I$13 - (I$13 + I$50 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$50 * 60 * 24) / I$12 * 90 / 24)) / (I$13 + I$50 * 60 * 24))	%H2	
54	time = 120 hours	%		0.03899		0.10405		0.18194	100 * ((I$13 - (I$13 - (I$13 + I$50 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$50 * 60 * 24) / I$12 * 120 / 24)) / (I$13 + I$50 * 60 * 24))	%H2	
55	time = 240 hours	%		0.03905		0.10406		0.18196	100 * ((I$13 - (I$13 - (I$13 + I$50 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$50 * 60 * 24) / I$12 * 240 / 24)) / (I$13 + I$50 * 60 * 24))	%H2	
56											
57	vent rate =	ft^3/min		120		60		60			
58	time = 3 hours	%		0.01943		0.05498		0.09619	100 * ((I$13 - (I$13 - (I$13 + I$57 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$57 * 60 * 24) / I$12 * 6 / 24)) / (I$13 + I$57 * 60 * 24))	%H2	
59	time = 30 hours	%		0.02496		0.06835		0.11955	100 * ((I$13 - (I$13 - (I$13 + I$57 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$57 * 60 * 24) / I$12 * 30 / 24)) / (I$13 + I$57 * 60 * 24))	%H2	
60	time = 90 hours	%		0.02602		0.06939		0.12138	100 * ((I$13 - (I$13 - (I$13 + I$57 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$57 * 60 * 24) / I$12 * 90 / 24)) / (I$13 + I$57 * 60 * 24))	%H2	
61	time = 120 hours	%		0.02603		0.06940		0.12138	100 * ((I$13 - (I$13 - (I$13 + I$57 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$57 * 60 * 24) / I$12 * 120 / 24)) / (I$13 + I$57 * 60 * 24))	%H2	
62	time = 240 hours	%		0.02603		0.06940		0.12138	100 * ((I$13 - (I$13 - (I$13 + I$57 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$57 * 60 * 24) / I$12 * 240 / 24)) / (I$13 + I$57 * 60 * 24))	%H2	
63											
64	vent rate =	ft^3/min		160		80		80			
65	time = 3 hours	%		0.01740		0.04771		0.08347	100 * ((I$13 - (I$13 - (I$13 + I$64 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$64 * 60 * 24) / I$12 * 6 / 24)) / (I$13 + I$64 * 60 * 24))	%H2	
66	time = 30 hours	%		0.01934		0.05192		0.09083	100 * ((I$13 - (I$13 - (I$13 + I$64 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$64 * 60 * 24) / I$12 * 30 / 24)) / (I$13 + I$64 * 60 * 24))	%H2	
67	time = 90 hours	%		0.01953		0.05206		0.09106	100 * ((I$13 - (I$13 - (I$13 + I$64 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$64 * 60 * 24) / I$12 * 90 / 24)) / (I$13 + I$64 * 60 * 24))	%H2	
68	time = 120 hours	%		0.01953		0.05206		0.09106	100 * ((I$13 - (I$13 - (I$13 + I$64 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$64 * 60 * 24) / I$12 * 120 / 24)) / (I$13 + I$64 * 60 * 24))	%H2	

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	B	C	D	E	F	G	H	I	J	K	L
2	Check of Calc Note: HNF-SD-WM-CN-114 Rev 0.										
3			1	2	3	4	5	6		Variable	Range
4	Tank		C-106	C-106	AY102 Before	AY102 Before	AY102-After	AY102-After	Formula	Name	Name
5			Best Est	Bounding	Best Est	Bounding	Best Est	Bounding			
69	time = 240 hours	%		0.01953		0.05206		0.09106	100 * ((I$13 - (I$13 - (I$13 + I$64 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$64 * 60 * 24) / I$12 * 240 / 24)) / (I$13 + I$64 * 60 * 24))	%H2	
70											
71	vent rate =	ft^3/min		200		100		100			
72	time = 3 hours	%		0.01562		0.04165		0.07286	100 * ((I$13 - (I$13 - (I$13 + I$71 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$71 * 60 * 24) / I$12 * 6 / 24)) / (I$13 + I$71 * 60 * 24))	%H2	
73	time = 30 hours	%		0.01562		0.04165		0.07286	100 * ((I$13 - (I$13 - (I$13 + I$71 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$71 * 60 * 24) / I$12 * 30 / 24)) / (I$13 + I$71 * 60 * 24))	%H2	
74	time = 90 hours	%		0.01562		0.04165		0.07286	100 * ((I$13 - (I$13 - (I$13 + I$71 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$71 * 60 * 24) / I$12 * 90 / 24)) / (I$13 + I$71 * 60 * 24))	%H2	
75	time = 120 hours	%		0.01562		0.04165		0.07286	100 * ((I$13 - (I$13 - (I$13 + I$71 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$71 * 60 * 24) / I$12 * 120 / 24)) / (I$13 + I$71 * 60 * 24))	%H2	
76	time = 240 hours	%		0.01562		0.04165		0.07286	100 * ((I$13 - (I$13 - (I$13 + I$71 * 60 * 24) * I$21 / 100) * @EXP(- (I$13 + I$71 * 60 * 24) / I$12 * 240 / 24)) / (I$13 + I$71 * 60 * 24))	%H2	

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