Fire Nomogram Use with Wildland Engineers Q-Ref.

PURPOSE

Fire Behavior Nomograms or predictive models have existed for a little over 50 years providing valuable information to fire operations and planning personnel so they can better plan, prepare, stage & use resources during an active fire based upon the Nomogram Outputs. However, some of the information in the Nomograms are cumbersome or of little practical use to the “average” single resource or firefighter on the ground without extensive classroom instruction and practice.

The information that is often of little (initial) practical use is the Heat per Unit Area (HPA), in BTU per Square Foot. Typically the Fires Rate Of Spread is given in Chains per Hour, yet to be more useful for operational personnel in the field some re-arranging of the figures to feet per second is necessary and can make the Nomograms a lot more useful in being able to determine the right amount and type of air/ground resources based upon the Heat Per unit Area. This conceptual document attempts to explain this concept and how to use existing resources to achieve the maximum cooling effect so that ground resources such as Crews, Engines, and Dozers can move in closer for more efficient suppression efforts.

There is a Wildland Apparatus Engineers Quick Reference Guide; that was developed for engine operators and pump operators to determine the BTU absorption capacity of water and how to match flow rates to the amount of heat being generated by a fire. This Document explains how to better use that Quick Reference Guide or Q-Ref along with the Fire Nomograms to boost efficiency of air/ground resources and suppression activity. WAE calls it, “FireBridge”. Construction of a Mathematical bridge to, “Bridge the gap”, between Plans (FBANS) & Operations for use at the lowest possible level.

numbers Footnotes on page 10

Fire Nomogram Use with Wildland Engineers Q-Ref.

Fire Nomogram Model 4 attached

Conceptual

1st. Example: Fuel Model 4, Chaparral (6Ft) Low wind speed

Slope 60%

20ft wind speed 15mph

Effective Mid flame wind speed estimated at 16mph.

Output? = (switch to high wind side)

Inputs: (Blue)

2nd Example: Fuel Model 4, Chaparral (6Ft) High wind Speed

(Just chosen arbitrarily for illustration)

Slope 60%

20ft wind speed 15mph

Effective Mid flame wind speed estimated at 16mph.

Dead Fuel Moisture 3% Live fuel moisture 120%

Outputs: (RED)

ROS ≈ 380 Ch/hr = 25,080 ft/hr = 418 ft/min = 6.97 ft/sec used (round to 7)

HPA ≈ 2,866 $BTUft^2$ (computed) but use 2,800 - 2,900

$BTU/ft/\,sec =$ HPA x ROS/ft/sec = 2,866 x 6.97 = 19,976

BTU/ft/sec range is between 2,800 x 7 to 2,900 x 7 = 19,600 to 20,300 (700 BTU spread)

For Fuel model 4 in this example, this is how the Aircraft Data in the Q-Ref would be used.

From the outputs again:

ROS ≈ 380 Ch/hr = 25,080 ft/hr = 418 ft/min = 6.97 ft/sec (round to 7)

HPA ≈ 2,866 $BTU ft^2$ *(computed) but use 2,800-2,900*

$BTU/ft/sec =$ *HPA x ROS/ft/sec = 2,866 x 6.97 = 19,976*

$BTU/ft/sec$ *range is between 2,800 x 7 to 2,900 x 7 = 19,600 to 20,300*

The next logical step in the determination & selection of the appropriate number and type of air resources for this discussion is based upon three main factors, all with several sub-factors interwoven.

- The *First* is obtaining the outputs on what the fire is doing by using the appropriate fuel model Nomogram (as above), in terms of Rate of Spread then converted to Feet Per Second along with its Intensity in BTU per Square foot.
- The *Second* is estimating the dimensions of the active fire line where the Cooling Agent and Retardant will be applied.
- The *Third* is determining the number of aircraft or drops required for each agent used based upon the calculation of the active fire area then using this along with the HPA to get the BTU being generated.

First, the ROS is in chains per hour as 380, you have to convert this to Feet/hour by multiplying 380 x 66 = 25,080 feet per hour. Then divide this by 3,600 to get Feet per second. That is your initial first step. You will obtain the ROS of 7 ft/sec. This 7 feet is your fire's "active" width.

Second, you need the length to get the area. We'll say for our example it is a mile (5,280ft) long fire line.

The Area is then 7*ft* x 5,280*ft* = 36,960 square feet.

Next, the BTU per second must be calculated.

Area of 36,960 *sq/ft* x 2,866 BTU/ft^2 = 105,972,360 BTU/sec. Our initial *First* & *Second* steps are complete.

The first step was using the Nomogram to get the final outputs to be used with the second and third factors and that second factor was the estimation of the fire area.

The third factor has 5 parts. 1 part requires you to know the fire's altitude and the water temperature to be used to cool the active fire area. This is important because the heat absorption capacity of water changes with two other factors; Altitude & Water Temperature. We'll say this is at 5,000 feet and then we'll use a water temperature of 50 degrees as in the Q-Ref found on pages 26 & 27(Or on pages 129 & 130 in the Lesson Book). This gives a Thermal Capacity of heat absorption per pound of water of 1,123 *BTU*/lb, once computed as explained on page 25 in the Q-ref(or page 128 in the Lesson Book).

The third factor, 2nd part, requires that you divide the fires estimated BTU generation (determined above), by the thermal capacity of water for the temperature and altitude.

This gives the *Pounds* of water required because the first set of numbers is based upon BTU per pound.

$$\frac{105{,}972{,}360}{1{,}123} = 94{,}325\ lbs\ of\ water.$$

Next, divide the 94,325 *Pounds* by 8.34 (pounds per gallon) to get the gallons required for knockdown.

$$\frac{94{,}325\ pounds\ required}{8.34\ pounds\ per\ gal} = 11{,}310\ Gallons$$

If you rounded to 106 million BTU, you would have got an answer of 11,318 Gallons.

The third factor, 3rd part. You refer to the Q-Ref and either select a single aircraft if one matches directly or exceeds the Gallon Requirement. As shown on either pages 26 & 27 of the Q-Ref single publication or pages 129 & 130 of the Lesson Book publication, the DC10 fixed-wing tanker holds 11,600 [1]Gallons. Or you could use the approach by taking the 3,000 gallon capacity for the type 1 tankers such as the BAE146, RJ85, MD87, etc., and divide the Gallons Required by the Gallons Carried to obtain the number of loads as shown below.

$$\frac{11{,}310\ Gals\ Req'd}{3{,}000\ Gals\ Capacity} = 3.77, round\ to\ 4 = \ Number\ of\ loads/drops$$

This tells you the number of [2]*Loads or aircraft* you will have to have to achieve good knockdown at a minimum. This is NOT extinguishment. This is Knockdown only. These loads "MUST" be dropped sequentially. Load and Return will not suffice.

Third factor 4th part. Another way to determine the appropriate number of resources is to go back to the originally calculated BTU generated and simply divide this figure by the BTU capacity shown in the Aircraft Data pages. i.e. 3,000 gallons is equal to 28,100,000 BTU.

$$\frac{BTU\ of\ Fire\ Generated}{BTU\ absorption\ of\ Aircraft} = \frac{105{,}972{,}360}{28{,}100{,}000} = 3.7 \text{ Round up to 4.}$$

For an example of this method, let us again take our example fires generated *BTU* output and then divide it by a figure from an aircraft with much smaller capacity and say that we do not have any large aircraft available.

$$\frac{BTU\ of\ Fire\ Generated}{BTU\ Absorption\ of\ Aircraft} = \frac{105{,}972{,}360}{12{,}170{,}000} = 8.7\ Loads\ or\ Aircraft$$

Therefore, if we take the combined *BTU* absorption capacity of say 9, CL215 (scoopers) Type 2 Fixed-wing aircraft that carry 1,300 gallons each, we'd get a *BTU* total of 109,580,094. More than our active fire line is generating. Therefore the number of aircraft and or aircraft loads will increase or decrease based upon what the capacity of each aircraft is and the amount of *BTU* being generated. The point is that all aircraft do not have to be the same type and capacity. The idea is to get the combined amount of *BTU* absorption regardless of the different types and models of aircraft being used.

Another such example is if all you have available are 5 seats at 800 gallons each, then, the result would look like this:

$$\frac{105{,}972{,}360}{7{,}500{,}000} = 14.2\ Loads \text{ (round to 15)}$$

This would further be broken up between the 5 SEATS so each SEAT needs to drop 3 loads, sequentially. Also to prove our *BTU* absorption capacity of 15 loads of 800 gallons of water works out, we do our math: 800 gallons x 8.34lbs = 6,672 Pounds of water. 6,672 Pounds x 1123 *BTU*/lb = 7,492,656 *BTU* per load x 15 loads = 112,389,840 *BTU* absorption. Why the 15 loads? How else would you carry .2 loads worth in addition to the 14? It must be an extra load.

Third factor 5th part. The Effective Area of Coverage an aircraft can/could provide can be estimated once you know the *BTU* per square foot and the *BTU* Capacity of the resource to be used.

For example $Fire\ Generated\ BTU/ft^2 = 2{,}866$. Aircraft *BTU* absorption capacity = 28,100,000.

$$\frac{Aircraft\ BTU\ absorption}{Fire\ Heat\ Per\ unit\ Area} = \frac{28{,}100{,}000}{2{,}866} = 9{,}804\ sq/ft$$

If we further take the *known ROS* in feet per second of 7 and then divide the 9,804ft^2 area, by 7*ft* ([5]The active fire width), we'll get an effective run length of:

$$\frac{9{,}804\ sqft}{7\ ft\ sec} = 1{,}400\ feet\ .$$

This is the maximum run length per aircraft and the run length would be a slight percentage less due to an efficiency factor. If we used say .95 for a 95% efficiency factor, then the effective run-length could be estimated at 1,400 x .95 = 1,330 feet. This is since being 100% on target for each aircraft, each drop on every sortie is simply not possible. There are too many variables that can affect drop accuracy. Note: If the terrain is rather steep & jagged, then maybe a .7 efficiency factor would be used. A 1,400-foot run multiplied by a .7 (70% efficiency factor) now is only 980 feet of effective run length. Re computing the number of aircraft/loads is then computed by taking that mile-long line and dividing by the 980 feet, which, you would end up with 5.38, so order up 2 extra aircraft for a total of 6.

Pending the "coverage level", will the 4 aircraft make a mile-long drop then? To be more accurate use a.9 or .95 multiplier to the 1,400 This re-computes the effective aircraft run to 1,330ft.

1,400 x 4 = 5,600 feet. YES!

1,330 x 4 = 5,320 feet. Yes!

[Updated 1-2022: Looking at the coverage levels, tank release rates, design, etc. and cup testing criteria would suggest the above method is not possible. Under this "current" system being used, we'd agree, however, keep in mind that it comes down to two main factors. 1. What the final Btu generation of the fire is producing and 2. Gathering enough Btu [6]Absorption capability on the operations side, to match the fire side. As was stated previously on the WAE website, delivery problems and issues for aircraft are not our concern. Our sole focus is to determine a simple match by estimation of the numbers and types of aircraft load capacities to the Fire Btu output figures. Thus the ideal coverage to match a HPA of 2,866 $Btuft^2$ would be closer to the following formula:

$$\frac{3{,}000\ \ gals}{9{,}804\ ft^2} = .306gal/ft^2$$

This .306 gals would be multiplied by the pounds per gallons of 8.34 to determine the total weight, which, comprises 2.552lbs. Then this 2.552lbs would be multiplied by the Btu Absorption capacity of water for the altitude and temperature which is 1123 Btu/lb.

$$2.552lb\ x\ 1{,}123Btu/lb = 2{,}865.896\ Btu\ per\ square\ foot$$

From this we can derive the gallons per 100 square feet. .306 x 100 = 30.6. Until we can control the drop pattern “Width” and narrow it down so that more of the cooling agent is DIRECTLY over the heat source, we’ll simply have to keep adding aircraft to the mix.

Once the Knockdown of the active flame front is achieved, then you have the LC95 loaded aircraft immediately drop in the same place, to place a CAP of burn inhibitor over the now cooled fuel. The remaining water content in the retardant along with the burn inhibiting characteristics of the retardant should provide a means for crews, Engines, and Dozers to move in to be more effective at control and containment efforts. After all, it is the BTU being generated that keeps such resources at bay and once this knockdown is achieved, due to the large-scale cooling effect, the other resources can move in closer.

Fighting fire in this manner is critical of the timing between aircraft due to the area involved and the amount of residual heat means flare-ups are highly likely.

The aircraft loaded with retardant should be in the air and in the vicinity near the same time as the aircraft with straight water. If you are planning on simply having aircraft load and return with the retardant you’ll likely find this technique to be sadly ineffective.

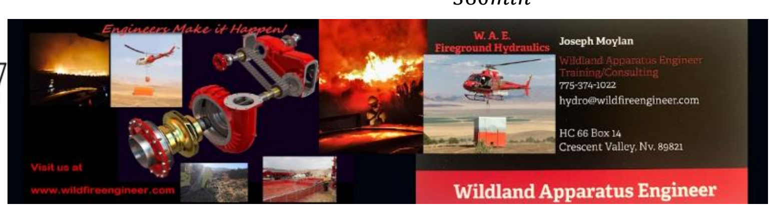
After spending the past several months reviewing [3]Rothermel’s & others Technical reports, the method described above is believed to offer up the most successful manner to fight large-scale fires with significant *BTU* generation. Lastly, the $BTU/ft/sec$ figures are the same as the Heat Per unit Area, they are accounting for the ROS. By dividing the $BTU/ft/sec$ figure by the rate of spread in *Ft/sec* gives you the HPA.

The Rate of Spread offers the instant ability to determine where the fire will be in the time frame it will take the aircraft to arrive on the scene to make [4]sequential drops. This should be viewed as that of a nozzle on an engine. If the BTU is too great, the nozzle is ineffective and you will not be able to engage or get close. Likewise, if there are only intermittent aircraft making drops of random sizes & times then this will have the same effect. The GPM must be matched to the BTU! [5]Wildland Apparatus Engineers Q-Ref pages 26 & 27.

All Fires Generate BTU and Water absorbs BTU. To be truly effective, we have to apply BTU absorption capability equal to or faster than the fire can generate! For example, simply having a 747 Super Tanker on hand loaded to max capacity of 19,000 gallons that takes from 4 to 6 hours to make a round trip, is only delivering an effective gallon per minute capacity of:

$$Egpm(4\ hour\ turn) = \frac{19{,}000gals}{240min} = 79$$

$$Egpm(6\ hour\ turn) = \frac{19{,}000gals}{360min} = 52$$



In this case, 79 Egpm, at the thermal capacity of water of 1,123Btu/lb is only 739,899.78 BTU

On the low side, 52 Egpm thermal capacity, is only 487,022.64 BTU

In this instance, it's not very effective if you're dropping LC95 in the trees if the floor is carrying the fire. It (LC95), gets hung up in the canopy and very little to nothing hits the carrier fuels on the forest floor. Further, with LC95, there is less water to absorb the heat. For example; in a full 19,000-gallon load of retardant, there are 3,454 gallons of LC95 and 15,546 gallons of water. The water is your greatest heat-absorbing agent and to be effective, you have to have multiple aircraft in the air to drop sequentially. As can be seen above, one aircraft of this size on a *load & return* every four to six hours is simply not effective because there is too much time between loads.

Even though in one drop 19,000 gallons of water absorbs 177.9 Million BTU, it will not be effective if you have a fire producing 100 Million BTU/Second when there is a 4-hour or 6-hour lag between drops. There is simply too much residual heat to be effective.

15,546 gallons of water absorbs 145,601,037 BTU, whereas 19,000 gallons absorbs 177,950,580 BTU. This is for 5,000 foot altitude & 50 degree water temp.

Also, I will point out that from 1946 to the present day, not a single technical report reviewed offers up a single method for how to provide suppression of fires or even a possible theory in the suppression of such in all of the reports to which have been reviewed to date. If there are any that state such suppression theories I would be very interested in seeing their approach.

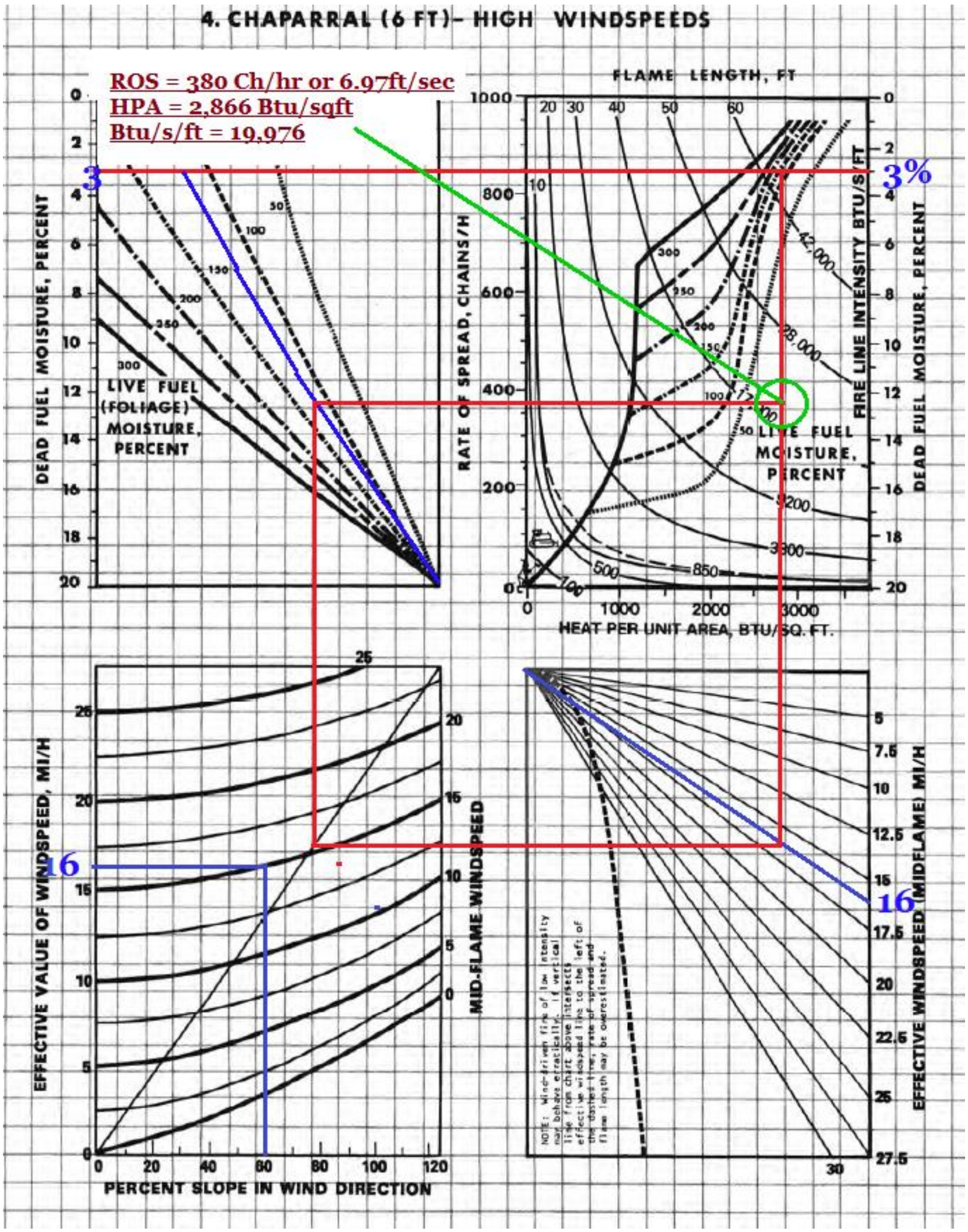
Written for Archive, June 2018 – April 2021

wildfireengineer.com

Wildland Apparatus Engineer, SP.

Joseph Moylan

Hydro@wildfireengineer.com



Blue = input figures, RED = output figures

Footnotes

1. The load capacity used herein may not be correct in actual conditions pending density altitude and aircraft load configuration etc.
2. The number of Loads calculated here is NOT for that of LC95 as LC95 does NOT have a calculated or established BTU/lb rating as of date. This only works for Water only loads.
3. Thanks to Molly Wright (Fire Ecologist) for bringing the awareness of the Rothermel Technical Reports and Other reports & Nomograms to my attention. This was a critical missing element in being able to conceptualize suppression resources and types with estimated fire behavior activity and possible theorized resource arrangement.
4. The Drops must be made in sequential order. Intermittency as normally performed will not provide the required cooling effect by way of the fact that the fire is generating heat continuously, yet if only one aircraft drops an amount of water, then leaves to re-load, in this case only 26% of the amount BTU generated is being absorbed. The adjacent heat radiation will simply re-ignite the fuel before the next drop returns. Sequential dropping is believed to be more akin to that of a constantly flowing nozzle providing exponential cooling capacity more closely matching that of what the fire is producing.
5. The active fire width could be replaced with a known drop width pattern that could be used in place of the fires active width and therefore a better estimate of aircraft run/drop length could be calculated as well as the number of loads required.

6. Aircraft Data from Q-Ref

Aircraft Type	Category	Cruise Speed		Capacity indiv		Cap Total	Btu total Cap
1,2,3	rotor/fix	Kts	Mph	LC95	Water	Gallons	Million Btu's
1 - RJ85	Fixed	380	437	545	2455	3000	28.1
1- BAE 146	Fixed	380	437	545	2455	3000	28.1
1-C130MAFF	Fixed	238	275	545	2455	3000	28.1
1-MD-87	Fixed	450	517	545	2455	3000	28.1
1-P3A	Fixed	330	380	545	2455	3000	28.1
1-L188	Fixed	310	356	600	2700	3300	30.1
1-C130	Fixed	238	275	727	3273	4000	37.5
1-737-300	Fixed	250	287	727	3273	4000	37.5
1-DC10	Fixed	490	564	2109	9491	11600	108.6
1-747	Fixed	490	564	3454	15546	19000	177.9
1-CH53E	Rotor	150	137	na	na	2000	18.7
1-CH46 sk	Rotor	121	140	na	na	224	2.1
1-CH47D	Rotor	119	137	na	nq	2000	18.7
1-S61	Rotor	133	154	na	na	1000	9.3
1-S64	Rotor	91	105	na	na	2650	24.8
1-S70i	Rotor	159	183	na	na	1000	9.3
1-kmax	Rotor	79	91	na	na	700	6.5
1-AS332L	Rotor	135	156	na	na	2000	18.7
1-B107Vertol	Rotor	121	140	na	na	1000	9.3
1-B234CHnk	Rotor	119	137	na	na	3000	28.1

Use with Fire Behavior Nomograms!

NOTE: The aircraft data sections for pp's 26 & 27, show listings for Maximum Gallon Capacities and may not be reflective of those actually used. The BTU figures are displaying BTU Capacity should those maximum capacities in water be available and utilized.

7. Absorption Capacity

BAE - 146, MD-87, RJ 85, C130MAFF, ETC

HEAT ABSORPTION CAPACITY OF WATER WORKSHEET

BTU's / Min, per Pound of water

(EXAMPLE)

Desired Flow (GPM)__500____ @ Temp(deg. est)__70____

Flow in GPM __500______ x 8.34 = __4,170________ lbs/minute

Boiling occurs at 212° Sea Level and Boiling occurs at 196.9° at 8,000ft. This works out to 1.84° per 1,000ft.

BOILING ________________ STEAMING ________________

(Temp to boil @ Alt) – (Tank Temp)

(970)BTU's/lb of water x (lbs/minute flowing) absorption in converting to steam

5,000 / 1,000 = 5.0
5.0 x 1.84 = 9.2
212.0 - 9.2 = 202.8
Temp to Boil at Alt = 202.8

204° - 70° = 134° each lb of water will be raised 134° to boiling point.
[B]
134 x 4170 lbs/min = 558,780 BTU/Min

ea. lb will be raised an additional 970btu in the conversion to steam from a boil.
[S]
(970) x (4170)lbs/min = 4,044,900 BTU/Lb

S 4,044,900
B 558,780
+ ________
4,603,680 BTU/MIN
x 60
____
272,220,800 BTU/HR

Desired Flow (GPM) **3,000** ____ @ Temp(deg. est) **50** ____

Flow in GPM **3,000** ______ x 8.34 = **25,020** ______ lbs/minute

Boiling occurs at 212° at Sea Level and Boiling occurs at 196.9° at 8,000ft. This works out to 1.84° per 1,000ft. 204° = 4,000ft., 202° = 5,000ft. etc.

BOILING ________________ STEAMING ________________

(Temp to boil @ Alt) – (Tank Temp)

(970)BTU's/lb of water x (lbs/minute flowing) absorption in converting to steam.

202.8 - 50 = btu/lb 152.8

[B]
152.8 ° X 25,020 = 3,823,056
Btu/lb Specific Heat | lbs/min(above) | btu/min

[S]
(970) X 25,020 = 24,276,906
lbs/min | BTU/min Latent Heat

[S] + [B] = TOTAL

Water Only

[S] 24,276,906
+
[B] 3,823,056
=
28,099,962 BTU/~~MIN~~ Total
x 60
= BTU/HR Total

Moylan - - Feb 20, 2021

BAE - 146, MD-87, RJ 85, C130MAFF, ETC

HEAT ABSORPTION CAPACITY OF WATER WORKSHEET

BTU's / Min, per Pound of water

(EXAMPLE)

Desired Flow (GPM)___500_____ @ Temp(deg. est)___70_____

Flow in GPM __500_______ x 8.34 = ___4,170__________ lbs/minute

Boiling occurs at 212° Sea Level and Boiling occurs at 196.9° at 8,000ft. This works out to 1.84° per 1,000ft.

BOILING__________________________ STEAMING_______________________

(Temp to boil @ Alt) – (Tank Temp) (970)BTU's/lb of water x (lbs/minute flowing) absorption in converting to steam

204° - 70° = 134° each lb of water will be raised 134° to boiling point. ea. lb will be raised an additional 970btu in the conversion to steam from a boil.

[B]
134 x 4170 lbs/min = 558,780 BTU/Min

[S]
(970) x (4170)lbs/min = 4,044,900 BTU/Lb

S 4,044,900
B 558,780
\+
4,603,680 BTU/MIN
x 60
272,220,800 BTU/HR

5,000 / 1,000 = 5.0
5.0 x 1.84 = 9.2
212.0 - 9.2 = 202.8
Temp to Boil at Alt = 202.8

LC95 as of this date has no published btu/lb absorption rating that WAE has been able to ascertain. Thus the BTU absorption capacity MUST be taken off of the water only portion of the entirety of the load.

3,000 / 5.5 = 545.45 (Concentrate = 545.45)

3,000 - 545.45 = 2,454.55 Gals of water, this is the largest thermal absorbant property of the mixed retardant. The other 545 gals is concentrate and must be considered as a burn inhibitor only. This reduces the total thermal absorbing capability of the entire load.

Desired Flow (GPM)_**2,455**____ @ Temp(deg. est)_**50**_____

Flow in GPM _**2,455**_____ x 8.34 = _**20,474.7**_____ lbs/minute

Boiling occurs at 212° at Sea Level and Boiling occurs at 196.9° at 8,000ft. This works out to 1.84° per 1,000ft. 204° = 4,000ft., 202° = 5,000ft. etc.

BOILING__________________________ STEAMING_______________________

(Temp to boil @ Alt) – (Tank Temp) (970)BTU's/lb of water x (lbs/minute flowing) absorption in converting to steam.

202.8_____ - _50____ = btu/lb_152.8____

[B]
152.8 ° x **20,474.7** = **3,128,534.16**
Btu/lb lbs/min(above) btu/min
Specific Heat

[S]
(970) x **20,474.7** = **19,866,601.41**
lbs/min BTU/min
Latent Heat

[S] + [B] = TOTAL

[S] **19,866,601.41**
\+
[B] **3,128,534.16**
=
22,995,135.57BTU/~~MIN~~ Total
x ___60__________
= BTU/HR Total

Mixed LC95

Moylan - - Feb 20, 2021

5.1 Million Less Btu than the same amount in 3,000 gallons of straight water