

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 and stage 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 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 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 hopefully boost the efficiency of air resources and suppression activity.

Moylan

Written for Archive

numbers Footnotes on the last page



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

HPA \approx 2,866 BTU ft² (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)



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

From the outputs again:

$$ROS \approx 380 \text{ Ch/hr} = 25,080 \text{ ft/hr} = 418 \text{ ft/min} = 6.97 \text{ ft/sec (round to 7)}$$

$$HPA \approx 2,866 \text{ BTU ft}^2 \text{ (computed) but use 2,800-2,900}$$

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

$$BTU/ft/sec \text{ range is between } 2,800 \times 7 \text{ to } 2,900 \times 7 = 19,600 \text{ to } 20,300$$

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 $380 \times 66 = 25,080$ 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 $7ft \times 5,280ft = 36,960$ square feet.

Next, the BTU per second must be calculated.

Area of $36,960 \text{ sq/ft} \times 2,866 \text{ BTU/ft}^2 = 105,972,360$ 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.



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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.

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

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

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

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 11,600¹ 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.

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

This tells you the number of ²Loads 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.

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



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 the capacity is of each aircraft and the amount of *BTU* being generated. The point is that it does not have to be all of the same size aircraft. 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:

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

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/ft²* = 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 9,804 ft^2 area by 7 ft (active fire width), we'll get an effective run length of

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



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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.

$$1,400 \times 4 = 5,600 \text{ feet. YES!}$$

$$1,330 \times 4 = 5,320 \text{ feet. Yes!}$$

[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 ⁶Absorption capability on the operations side, to match. 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 *Btuft²* would be closer to the following formula:

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

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.

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

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]



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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 ³Rothermel'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 ⁴sequential 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*! ⁵Wildland 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:

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

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



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In this case, 79 Egpm at the thermal capacity of water of 1123 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. 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.

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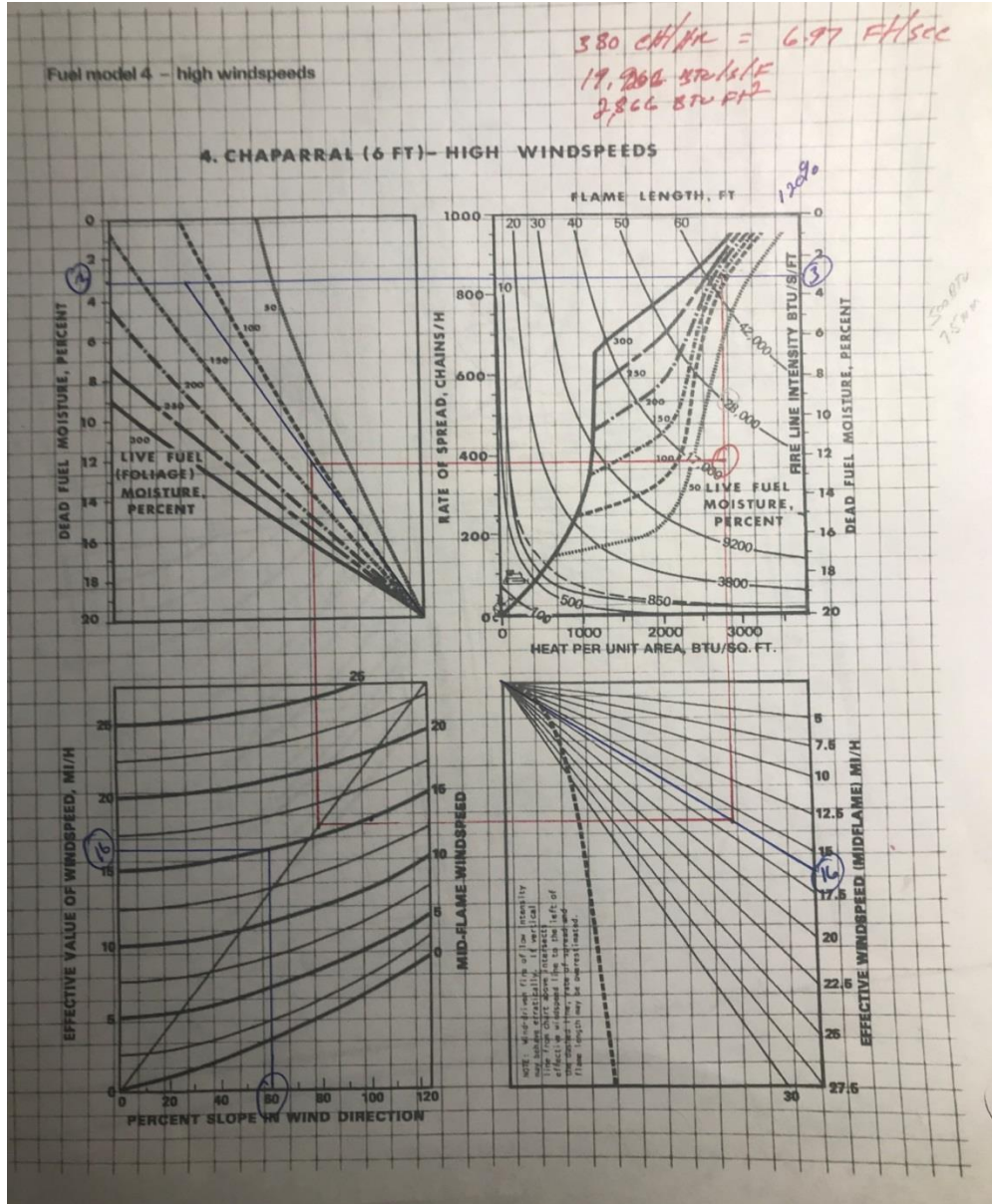
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Blue is input figures, RED is output figures

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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 M.C.Wright 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.



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5. Aircraft Data from Q-Ref

| Aircraft Type | Category | Cruise Speed | | Capacity indiv ⁷ | | Cap Total | Btu total | | |
|---------------|----------|--------------|-----------|-----------------------------|-----|-----------|-----------|---------|---------------|
| | | 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 | na | 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.



6 Absorption Capacity

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.

each lb will be raised an additional 970btu in the conversion to steam from a boil.

[B]

134 x 4,170 lbs/min = 558,780 BTU/Min

[S]

(970) x (4,170)lbs/min = 4,044,900 BTU/Lb

*5,000 FT Alt = 5 x 1.84
1000 G = 9.2*

*Sea level 212° - 9.2 = 202.8
Temp to boil @ sea*

BAE - 146 - 3000 Gallon/WATER

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

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

(substitute Aircraft Load)

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 *3,823,056*

STEAMING *29,276,906*

(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 lbs/min(above) btu/min
Specific Heat

[S]

(970) x 25,020 = 29,276,906
lbs/min BTU/min
Latent Heat

[S] + [B] = TOTAL

*[S] 29,276,906
+
[B] 3,823,056
= 33,099,962 BTU/MIN Total
x
60min
= 1,985,997,520 BTU/HR Total*



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.

each lb will be raised an additional 970btu in the conversion to steam from a boil.

[B]

134 x 4,170 lbs/min = 558,780 BTU/Min

[S]

(970) x (4,170)lbs/min = 4,044,900 BTU/Lb

Handwritten:
5000 Ft ALT
1000 = 5 x 1.84
G = 9.2
212 - 9.2 = 202.8°
Temp To Boil @ 5K

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

Handwritten:
BAE - 146 RETARDANT
3000 / 5.5 = 545
3000 / 5.5 = 545 ← Concentrate
2,455 ← Water

Desired Flow (GPM) 2,455 @ Temp(deg. est) 50

(substitute Aircraft Load)

Flow in GPM 2,455 x 8.34 = 20,474 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 3,128,427

STEAMING 19,865,922

(Temp to boil @ Alt) - (Tank Temp)

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

Handwritten: 202.8 - 50 = btu/lb 152.8

[B] 152.8° x 20,474 = 3,128,427
Btu/lb lbs/min(above) btu/min
Specific Heat

[S] (970) x 20,474 = 19,865,922
lbs/min BTU/min
Latent Heat

[S] + [B] - TOTAL

[S] 19,865,922
+
[B] 3,128,427
= 22,994,349 BTU/MIN Total
x 60min
= BTU/HR Total

Handwritten:
545 GALS of concentrate
It's no published BTU/lb rating
As of Date we know of!

Handwritten: 5.1 mit less BTU Absorption

Moylan -- Jan, 2022 WAE Fire Hydraulics - wildfreengineer.com

