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Snow as a fire-fighting agent.

In this paper we're looking at the potential of snow as a fire fighting agent.
We can split this topic into two parts. Firstly, it is worthwhile to examine the properties of snow and why it would be useful in controlling and/or extinguishing a range of fire types. Secondly, we must address the engineering challenges of producing snow in the hot and often remote or confined environments where we may encounter problem fires.

Fire and Snow

Snow is the name given to frozen water formed by condensation and freezing in the atmosphere. Independent snow formation requires extremely low temperatures and results in the freezing of water droplets which provide the nucleus for further crystal growth formation. At higher temperatures close to zero degrees Celsius the presence of a nucleating particulate is required to start the formation of ice crystals. This is the principle of commercial snow making machines.

Surface Area

Under a microscope, snow flakes have a fractal pattern, meaning the surface area to volume ratio is extremely high. This ratio is a very important factor when designing a fire fighting agent because of the way heat is transferred across a boundary. Heat energy transfer across a boundary is expressed by the following formula:

$$H = U.A\Delta T$$

Meaning, heat transfer is proportional to the surface area of the boundary (A), and to the temperature difference across it (ΔT or delta T, meaning the difference between the two temperatures)[1].
For example, commercial watermist fire fighting systems expel water at extremely high pressures (of up to 100 atmospheres of pressure or more) which creates a very fine mist of water droplets (each droplet smaller than 0.15mm).
The high surface area to volume ratio of these tiny droplets mean they absorb heat and evaporate at a much faster rate than conventional sprinkler systems. This results in a high rate of energy absorption and hence highly effective fire control. Similarly, the fractal nature of snow crystals means their rate of heat absorption would be many times greater than water droplets.
Returning to our equation for Heat energy transfer, our third term is the temperature difference. Since our snow flakes are below zero degrees Celsius, we have further increased our temperature difference across the absorption boundary and thus increased our rate of heat absorption.

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[1] U is called the heat transfer coefficient and describes the properties of the materials – we can ignore this for simplicity and take a qualitative approach rather than quantitative

Energy Gap

The term energy gap is used here *loosely* to describe the difference between the water in its presented form (solid) and final form (water vapour). This quantity is important because one of the goals of fire control is to absorb energy from a fire in order to reduce its temperature. This prevents further ignition to surroundings (for example it may keep the local temperature below the flash point or pyrolysis temperature of local fuels) and allows closer approach by fire fighting personnel. Modern hose fire fighting techniques include a wide spray short blast to provide a region of relatively cool air to prevent flash back and protect the fire fighter. This would be particularly effective with the use of the extra cold snow blast.

*something about energy absorbed by ff agent is thus not absorbed by fuel.

A few quantitative facts[2]:
The amount of energy required to heat 1kg of water from 15 to 16 degrees Celsius is 4.187 kJ. This value changes with temperature but is useful as a rule of thumb for rough calculations, and we call it the specific heat capacity (because it's how much heat energy it can hold, per kilogram per degree of temperature change). Conveniently, water has a relatively high heat capacity compared to many common substances and this makes it a good fire fighting agent but is also why water heating represents a large factor on your home electricity bill!
The amount of energy required to melt 1kg of ice is 335kJ. That is, melting 1kg of ice takes the same amount of energy as heating 1kg of water 80 degrees Celsius.
Since water is only useful as a fire-fighting substance so long as it is in liquid form (I will touch on oxygen displacement later), snow absorbs approximately twice as much energy per kg as water at 20 degrees C, prior to evaporation. Thus the energy gap between snow and steam is twice that of water at 20 degrees Celsius and steam.
However for comparison, the amount of energy required to boil/vapourise 1kg of water is 2501 kJ, which is the equivalent of heating 6 kg of water 80 degrees Celsius. This should be considered when evaluating the effectiveness of snow as a fire fighting agent, since when compared to the enthalpy of vapourisation (the energy gap between liquid and gas), the energy gap down to frozen water is less significant.

Fluid velocity

Many commercial fire fighting products such as water mist, inert gas and fire hose systems depend on a high fluid velocity to aid in fire penetration and to attack the base of the fire, cooling or smothering the fire. The high velocity of snow production units may aid in these processes. As we heat ice, it remains at 0 degrees Celsius until completely melted. By delivering a high velocity stream of ice to the base of the fire, it may be possible to rapidly decrease the fuel temperature, slowing the process of combustion and controlling the fire. This is a speculative point, since heat from a full sized pan fire should not be underestimated, and the quantities of ice we can produce may be limited.

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[2] Refrigeration – Introduction *Danfoss AC-DSL, HBS November 2007*

Furthermore, since air is the medium for snow transport, this will provide more oxygen for the fire.

In conclusion to this section on snow as a fire fighting agent we can summarise as follows:

The delivery of high velocity snow may be an ideal fire fighting product for the following reasons:

- High rate of flame penetration, targets and cools fuel source directly.
- Low temperature aids cooling of fuel.
- High surface area aids rapid heat transfer significantly and makes better use of the same volume of water.
- Low temperature further aids in rapid heat transfer.
- Additional energy requirement to raise temperature of snow through phase change solid-to-liquid as well as liquid-to-gas.
- Depending on the use of air or inert gas, may displace oxygen, choking the combustion process.
- As snow evaporates, steam further displaces oxygen.

Drawbacks of using snow as a fire fighting agent:

- May be less effective against Class B (liquid) fires.
- If air is used as transport method then this provides oxygen, exacerbating fire.
- Multiple engineering challenges outlined in Section 2.

<u>Engineering Challenges</u>

Now that we have established good reasons for exploring snow as a fire fighting agent, we can explore how we might make it possible.

Firstly and most importantly, conventional snow production systems depend on low temperature low humidity environments to freeze the water, rather than by refrigeration. Typically the temperature must be at a maximum of 6 degrees Celsius (at no greater than zero humidity) for snow to form[3]. This severely restricts our ability to create useful snow by conventional means in the kinds of hot environments where we are likely to encounter problem fires.
This is, and will continue to be the monkey on our back when attempting to design this system.

To reduce 1kg of water from 15 C down to ice, we must accomplish two things:

1. Cooling to zero degrees Celsius
2. Phase change to ice at constant temperature.

[3] http://en.wikipedia.org/wiki/Snowmaking

Cooling to zero degrees Celsius requires the same amount of energy (ideally) as heating the water in the opposite direction. As stated in Section 1, this amount of energy can be approximated as 4.187 kJ of energy, per kilogram of water, per degree Celsius. So to cool 1kg of water from 15 degrees Celsius to 14 degrees Celsius takes 4.187 kJ of energy. To cool it all the way to zero requires fifteen times that.
So, 15 x 4.187 kJ per kilogram of water, which equals 62.805kJ per kilogram.
Then we must make a phase change from liquid to solid, which as stated in Section 1, equals 335 kJ per kilogram.
Thus our total (absolute minimum!) energy requirement is 335 + 62.8 kJ, let's say:

398kJ per kilogram to turn water into ice.

Fortunately, refrigerators only have to move heat from a cold medium to a hot medium, so we're not being limited by thermodynamic efficiencies[4] like in heat engines and so on. Modern refrigerators typically have a high rate of effectiveness so we can realistically expect something close to this figure for our energy requirements. Let's look at an example.

Example: A Scots Ice C 2148-ASR ice machine produces 884kg of ice per day.[5]
Since our energy requirements to turn water into ice is 398 kJ per kg.
So for that 884kg, our total energy is 351,382kJ. Over a course of an entire day (24x60x60 seconds), our power consumption should be:
351,382kJ / (24x60x60s) = **4.1kW**. Indeed the unit runs on just a **4kW** power supply.
We can use these figures to determine our approximate power requirements for producing ice. 884kg per day is only around **10 grams of ice per second**. This is with a large ice machine operating at a full 4kW (home outlets can supply around 2.4kW before blowing a fuse). Clearly our power requirements for any kind of significant ice flow will be substantial.

So to be clear, to produce just 10 grams of ice per second (ideally) we require a 4kW power supply, which is the approximate power output of a small portable generator or scooter engine.

These power requirements are fairly prohibitive. For example if we wanted to half-match our 240LPM fire hose for water output, we'd require a 1600kW plant just to produce the ice. This is enough to power approximately 1000 homes, or 2-and-a-bit Formula-1 racing engines at full power, or one and a half M1 Abrams battle tanks.

This doesn't mean it's impossible. A GE T700 gas turbine engine costs $328,000, outputs 1200kW and is designed to fit in a helicopter. That shaft power could produce, potentially, 3kg of ice per second which is comparable to our typical fire hose output. Similarly, Detroit Diesel 1000kW generator sets can be found for under $100,000 and are designed to be towed by truck. Engines in this range burn between $500 and $1500 of fuel per hour.

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[4] For lack of a better explanation, just understand that refrigeration is measured by "effectiveness" at moving heat whereas heat engines like in your car are measured by "efficiency" of converting heat into motion.
[5] http://www.scotsice.com.au/scotsman_ice_maker_machine.php?category=big+ice

To match the effectiveness of conventional water spray fire fighting systems we require a unit the size of a semi-trailer, costing a great deal to build and operate.

Conclusion

The author found this investigation extremely interesting however feels that the size requirements make snow making an impractical and costly method of fire fighting compared to conventional liquid fire fighting techniques.

It was surprising to find just how effective snow could be as a fire suppressant, when considered using the principles of modern fire fighting. The high surface area and large energy required to vapourise make it ideal for rapidly cooling gases, extinguishing fire, displacing oxygen, cooling boundaries and preventing re-flash.