Engineering Units in the Process Heating Workplace

How handy are they to visualize and use?

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Whether you are designing, specifying or operating a process you will need an instinct for the nature and size of engineering units.
Let's look at some of the units in common use, get a feel for how big they are, how you can best manipulate them and minimize the problems of mixing them.
A web search for "Engineering Units" shows conversion programs and utilities dominating the returns. One offer claims "supports over 400 000 conversions" It is no surprise that the obstacle course of different units can impede even endanger your day-to-day work.
You probably don't need reminding of the 23 mile glide and safe crash landing of a Boeing 767 in Gimli Manitoba, out of fuel because of a miscalculation between litres and fuel weight. Or of the $125M Mars Climate Orbiter, lost owing to confusion between metric and non-metric units.

TEMPERATURE

The Kelvin scale goes from absolute zero 0K (zero kelvins), through 273.15K called the ice point, through 373.15K, called the steam point, where water begins to boil, at normal atmospheric pressure. I hesitate to say where it ends. The unit K is called the kelvin not the degree kelvin and is the same size as the Celsius degree. Temperature difference is also given in kelvins rather than ºC.

The Celsius scale takes its zero (0ºC) at the ice point and 100ºC at the steam point. It follows the Kelvin scale but with a 273.15K downward offset.
The Fahrenheit scale is derived from $T_f = 9/5\ T_c + 32$
This puts the ice point at 32ºF and the steam point at 212ºF

WHAT DO DIFFERENT TEMPERATURES FEEL OR LOOK LIKE?

Example	**ºC**
Melting ice	0
Hot coffee, just sippable	55
1250W hairdryer (4cm outlet)	100
Lifting out a boiled egg	100
350W portable hot air gun (1cm nozzle)	350
2 kW Stove ring glowing dull red, to eye not finger	600
2 kW Stove ring glowing bright red `` ``	900
100W tungsten lamp filament (to the eye)	2500

Lifting out a 100ºC boiled egg feels much hotter than the 100ºC hairdryer outlet because of the fast heat transfer of water to the fingers.

FORCE, ENERGY AND POWER

If you accelerate mass of one kilogram at 1m/s/s ($1m/s^2$) you will need a force of one **newton.** The gravitational force on a 102g apple (a bit less than ¼ pound) is about one newton. Think of Isaac Newton.
If you exert a force of one newton through a distance of 1m you will expend energy equal to **1J** (one joule).
If you maintain this at a rate of 1J/sec your **power** level is **1W** (one watt). So 1W maintained for 1sec delivers 1J
Note that energy is the same stuff whether it is mechanical, electrical, thermal or chemical so you can use the same units.

SPECIFIC HEAT is the energy required to raise the temperature of one gram of a substance by 1ºC or 1kelvin. It is commonly expressed in gram calories and the value for water is 1. All other substances have values less than 1. When expressed in J/g º C the value is 4.18 times the gram calorie value.
Specific heat is somewhat dependent on temperature but this can usually be ignored for small temperature ranges. The specific heat of water expressed in kg calories is of course 1000 and the kg calorie is the one used by weight watchers.

HOW MUCH ENERGY DO YOU NEED TO HEAT WATER?
Fig 1 shows a power source applied to 1g of ice, starting at -10 º C and maintained long enough to turn all the ice to water vapor.
Stage A. Ice is heated up from –10 to 0 º C. The specific heat of ice around this temperature is about 2.09 J/g. º C.
Energy input = mass x specific heat x temperature rise i.e. 1 x 2.09 x 10 = 20.9 J (Joules).
The ice has not yet started to melt.
Stage B. The ice/water mixture remains at 0 º C (even though heat is being added) until all the ice melts. The heat required to melt the ice is mass x latent heat of fusion i.e. 1 x 333 = 333J. (the latent heat of fusion of water is 333J/g).
Stage C. The rise from 0 to 100 º C involves no phase-change to the water and all the applied heat of 419J is used in raising the temperature.

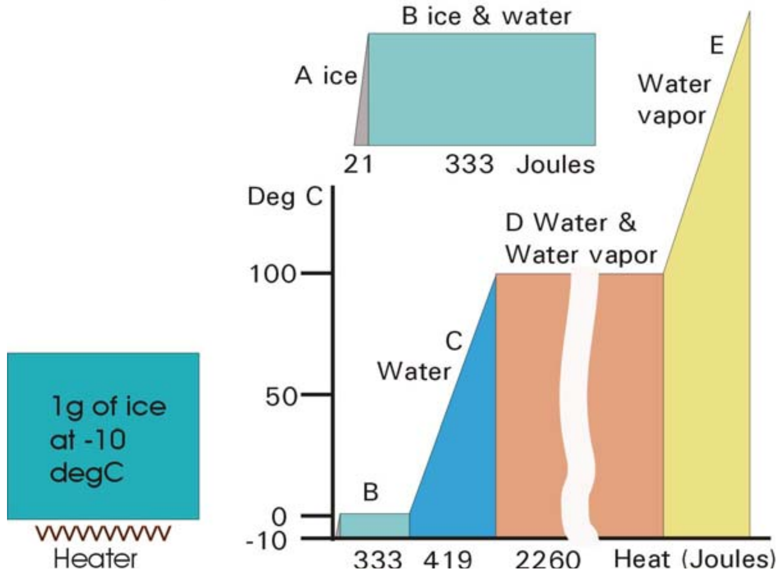

Fig 1

Specific heat of water is about 4.19 over this range.
Stage D. Another phase change occurs as the 1g of water at 100 º C changes to 1g of steam at 100 º C.
This takes 2260J. (2260J/g is the **heat of vaporization** for water).
Stage E. Heat is being added with no phase change occurring. Using a specific heat of 2.01 J/g º C, it takes 2.01J for every º C that the steam temperature increases around this point on the graph.

The high specific heat and heat of vaporization of water make it an excellent medium for process cooling or dumping waste heat.
The joule and gram are not a handy size for the workplace. The kilowatt (kW), the kilowatt hour (kWh) and kilogram (all metric units) are easy to visualize and well accepted world wide in the SI (International System)

HOW MUCH ENERGY DO YOU NEED TO HEAT AIR?
Let's calculate the energy required to raise 1 m^3 from 0 to 100 º C.
The specific heat of air is about 1 J/g º C. The density at normal temperature and pressure is 1200g/m^3
Energy = mass x specific heat x temperature rise =1200 x 1 x 100 = 120000J
Not a handy unit so let's divide by 3600 to get 33.3 watt hours (Wh)

HOW MUCH POWER DO YOU NEED TO HEAT A CONTINUOUS AIR STREAM?
Based on the above calculation, 1 m^3/h heated through 100 º C needs 33.3Wh/h = 33.3W. Now you can scale up or down and convert to your preferred units.

The Ton as a Cooling Unit
I want to clarify here an antique engineering unit called the **ton.** It is still used in the refrigeration and air conditioning industry but in this context it is not a unit of mass**.** It expresses a **rate** of removal of heat, which makes it a unit of **power,** negative though it is**.** This brand of ton equals **3.5 kW** or **12000Btu/h**. Feel the output of three 1.2kW hair dryers and imagine a cold air register putting out the equivalent chilling action. That's a ton.
Its origin is with the ice delivery man. It is the **cooling rate** obtained in fully melting a **short ton** (2000lb) of ice over 24 hours.
Another figure from the cooling industry is the **energy efficiency ratio** (EER) It is not true to call it a unit. It is defined as the output in Btu of a cooling system divided by the input in Wh.
If you were to invent this ratio today you would use the same engineering unit for both input and output – being the same stuff, and EER would be a number not a Btu per Watt hour.
In modern cooling systems you will see EERs around 10 and up. An EER of 10 would translate to about 3 if you used the same unit for input and output.

We now turn to totting up the energy requirements of a heat process and the challenge of comparing energy prices.

Say you are designing or constructing a new heating process.
Before you start calculating, pause a while. There is no better guide than your practical experience and design and performance records of a similar process. It could be one that you have operated or designed. If there isn’t a close match in your plant it may be well worth the trouble to locate a similar process and drive out to examine it.
In any case, you would still like to know where the heat input goes. First you need the mass, specific heat and temperature rise of all parts of the process. Same for the work and any heat transfer medium. Then the various heat losses at working temperature. These include 1. Convection – e.g. flue gases and air throughput. 2. Surface radiation and convection to the environment. Losses can be hard to calculate so this is where you apply experience, asking around then testing.
Now you can determine both the kWh input needed to reach working temperature and the kW to maintain it. Next, ensure that you have the power to reach temperature fast enough to maintain the production rate that you want. However, some loads demand a slow, controlled heat-up rate and a defined hold time. First, to avoid thermal shock to the process and the work. Then to allow heat to soak thoroughly into the work. Under these kinds of restraints there isn’t much you can do to speed production but there is a possible good side-effect. If you are using electric heating, your electric metering could record a restricted peak start-up power and save money on the demand charge component of your bill. You will not necessarily use less energy per batch.

PAYING FOR YOUR ENERGY

So you have worked out your energy requirements and made a provisional choice of heat source. You may change that choice when you see the heating costs. Be warned, comparing energy costs is not easy. First, vendors cannot agree on a common unit for pricing energy. Then the degree of concealment and convolution in billing will defeat your easy choice of best buy. The pricing formula varies with fuel, vendor and your location.
Oil is sold by the liter or gallon and delivery may be a separate item.
You need to know the **calorific value** (CV), typically given in Btu/gallon.
Natural gas sells by the cubic foot or cubic metre and the CV could be given in BTU/ft^3 or MJ/m^3. You may not find the CV of either oil or gas on your bill

or quotation or the delivery charge.

Electrical energy sells by the kWh, perhaps with an off-peak discount, and possibly a monthly charge per kVA of maximum demand. Sometimes the advertised cost per kWh omits the transmission charge and sales tax but these are rolled in to your monthly bill with no breakdown shown. These roll-ins can double the posted price.

Specific Heats at Normal Temperature and Pressure

Substance	**J/kg°C**	**cal/g°C**
Aluminum	900	0.215
Beryllium	1830	0.436
Cadmium	230	0.055
Copper	387	0.0924
Germanium	322	0.077
Gold	129	0.0308
Iron	448	0.107
Lead	128	0.0305
Silicon	703	0.168
Silver	234	0.056
Brass	380	0.092
Wood	1700	0.41
Glass	837	0.200
Ice (-5 ° C)	2090	0.5
Marble	860	0.21
Ethyl Alcohol	2400	0.58
Mercury	140	0.033
Water	4186	1.00

What does power feel or look like?

Source	**kW**
Tungsten halogen spot lamp	0.05
Hair dryer	1.2
Portable warm-air heater	1.5
4-slice toaster	1.5
Clothes dryer	3
Hot shower	8
50 000 BTU/h barbecue	15
Hot kitchen faucet full on	25
2litre 150hp automobile	112