Ignition of Wood

and

Truck Insurance v. MagneTek

FS&T

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Outline of presentation

1. Types of ignition: due to external heating vs. self-heating
2. Principles of external ignition
3. Ignition of wood under external heating
4. Principles of self-heating
5. Ignition of wood due to self-heating
6. Lessons to be learned from *Truck Insurance v. MagneTek*
7. Summary from the point of view of product design/installation defects

Types of ignition:
External vs. self-heating

- We start with general principles pertinent to ignitable substances and then go to specific information for wood
- Most ignitions are due to external heating
  - *Example: lighting a newspaper with a match.*
- Some ignitions are due to self-heating
  - *Example: haystacks stacked under improper conditions*

External ignition…

- When an ignitable solid is heated by external heating and ignites, this can happen in two ways:
  - (1) ignition in the gas phase (flaming ignition); this is the most common way
  - (2) ignition at the surface (glowing ignition); this is less common, but wood is one of the materials that is capable of this external-ignition mode.

External ignition: Gas phase (flaming ignition)

- This is a two-step process:
  - (1) the material pyrolyzes under the effect of heat and releases flammable or combustible vapors
  - (2) the vapors mix with air and ignite either because they are very hot (autoignition) or ignite because a localized ignition source is present (piloted ignition).

Important definitions

- **Pyrolysis**: “Decomposition of a substance by the action of heat” (**Oxford English Dictionary**; from Greek “loosen by fire”)

- **Pyrolysis**: “The chemical degradation of a substance by the action of heat.” (**Ignition Handbook**, by Babrauskas)

- **Pyrolysis**: “Transformation of a compound into one or more other substances by heat alone, i.e., without oxidation” (**Hawley’s Condensed Chemical Dictionary**)

Discussion…

- Note that there is a subtle, but important difference between how the term is used by chemists, versus fire safety professionals
    - In chemistry, “pyrolysis” is a process that occurs in the absence of oxygen
    - In fire science, “pyrolysis” is used in the same way as in the Oxford English Dictionary—there can be oxygen, or no oxygen

…Discussion

- When they wish to denote the chemical degradation of a substance in the *presence* of oxygen, chemists refer to “**oxidative pyrolysis**”

- *Pyrolysis* is the noun; *pyrolyze* is the corresponding verb

- *Pyrolysate* is the material which is produced due to pyrolysis, in other words, it is the gaseous material which is driven off

Definitions…continued…

- **Autoignition**: “Initiation of combustion by heat but without a spark or flame.” (NFPA 921)
  - It is also normally understood that the heat is to be applied uniformly; thus, ignition facilitated by localized hot surfaces is a form of piloted ignition, not autoignition.
  - **Self-ignition** is a synonym, but it is best not to use this, because it is sometimes also taken to mean “spontaneous combustion”

…Definitions…continued

- **Piloted ignition**: “Ignition of combustible gases or vapors by a secondary source of energy, as by, for example, a flame, spark, electrical arc or glowing wire.” (ISO Standard 13943, Fire Safety - Vocabulary)

…External ignition: Gas phase…

- Pyrolysis causes molecules to break apart
- Small fragments break off from large molecules
- For most common materials, these fragments are molecules that contain primarily carbon and hydrogen atoms
- A heated, small molecule containing primarily carbon and hydrogen atoms will normally be a flammable/combustible vapor
- Hydrogen atoms are easier to break off than carbon atoms, so what remains of the solid is a carbonaceous char

…External ignition: Gas phase

- The flammable/combustible vapor molecules driven off from the solid will then ignite, under suitable conditions, if either:
  - The system gets so hot that autoignition occurs; or
  - A flame, spark, etc. is introduced in a suitable place
    - “Suitable place” is a location where the mixture of air and pyrolysates is within its flammability limits

External ignition: Glowing ignition…

- Most ignitable substances are NOT capable of glowing ignition.
- But a few substances are
- Wood (including wood products, and some vegetation, agricultural products), charcoal, and metals are the only substances a fire investigator is likely to encounter that are capable of glowing ignition

…External ignition: Glowing ignition…

- Glowing ignition means initiation of glowing combustion
  - **Glowing combustion**: “Luminous burning of solid material without a visible flame” (NFPA 921)
- Glowing combustion means that oxygen molecules from the air react directly with the material at the surface of the solid; thus the chemical reaction does not involve pyrolyzed gases

…External ignition: Glowing ignition…

- Smoldering is a form of glowing combustion
  - **Smoldering**: Self-sustained glowing combustion. A more precise definition is: “A propagating, self-sustained exothermic reaction wave deriving its principal heat from heterogeneous oxidation of a solid fuel.” (**Ignition Handbook**)
- Thus, smoldering and glowing combustion describe the same chemistry, but glowing combustion may be forced (by external heat source), while smoldering is, by definition, self-sustained.

…External ignition: Glowing ignition

- Both laymen and fire service personnel often use “smoldering” to mean “burning with only small flames”
  - This is NOT the meaning in fire science, so it is important for fire investigators to appreciate the distinction.
  - Smoldering combustion, in fire science, means an absence of flames
- But the situation in still-burning fire debris is complicated since, in fact, both smoldering and flaming combustion are probably going on at the same time.

External ignition: Ignition temperature…

- Ignition temperature is **NOT** a chemical constant of a substance (the way that, say, the boiling point or the melting point is)
- For **flaming ignition**, theories, in fact, indicate that you should not expect ignition to occur at a fixed temperature, if you vary the problem conditions (for example, the heat flux applied)
  - But experimental studies and theories both indicate that, over a wide range of heat fluxes, there is often only a small change in T_{ig}.
  - Thus, the approximation is often made that T_{ig} = constant and values are tabulated on that basis.

…Ignition temperature

- For **glowing ignition**, theory and experiments both indicate that the temperature at which a material will ignite *decreases*, as the heat flux applied to it decreases.

- Thus, it is only possible to speak of a single ignition temperature for glowing ignition if we specify that we are only interested in the lowest heat flux, lowest temperature condition (or else specify a particular heat flux of interest).

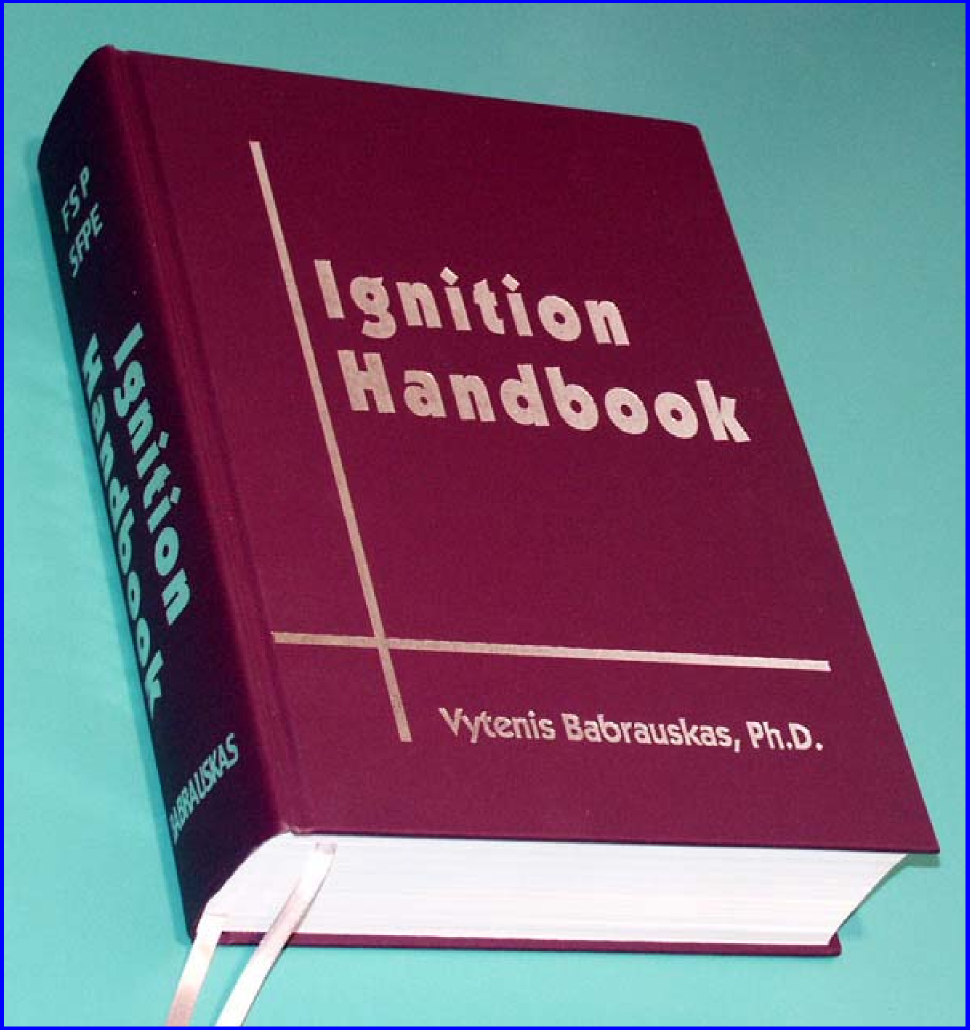
Uses for ignition temperature

- What are the uses of knowing an ignition temperature?
  - As input data into a calculational/predictive engineering model
  - In an attempt to conclude that an object cannot be ignited from a heater, if the heater's temperature is less than the T_{ig} of the object.
    - The latter is a concept which is applicable only if self-heating does not play a role; we shall return to this issue later.

External ignition: Data on wood

- Brief summary will be given here
- Details are available in:
  - Babrauskas, V., Ignition of Wood: A Review of the State of the Art, *J. Fire Protection Engineering* **12**, 163-189 (2002).
  - Babrauskas, V., **Ignition Handbook**, Fire Science Publishers/Society of Fire Protection Engineers (2003).
  - Both are peer-reviewed, scientific publications

Ignition Handbook



External ignition of wood…

- Prior to my research in this area, the topic seemed to be quite confusing, since:
  - There was a huge spread in the published values of ignition temperatures; and
  - The role of glowing ignition versus gas-phase ignition had not been systematically explored.

Historical note

- Wood has been the material whose ignition was of most interest to man ever since the beginnings of recorded history
  - The Romans were studying fire-retardant treatments to reduce the potential for ignition
  - Quantitative studies of wood ignition temperature go back at least to 1887.

Results from research studies...

- The results from examining a very long list of papers giving results for T_{ig} of wood were published in the two references cited.
- Excluding one outlier, the range of reported results is:
  - Piloted ignition 210 - 497°C (410 - 927ºF)
  - Autoignition 200 - 510°C (392 - 940ºF)
- Clearly, T_{ig} for wood is not just a unique, fixed constant.

Factors that might account for T_{ig} data spread...

- The definition of ignition that is used
- Piloted vs. autoignition conditions
- The design of the test apparatus and its operating conditions
- Specimen conditions (e.g., size, moisture, orientation)
- Species of wood.

…Factors that might account for T_{ig} data spread

- Outcome of research study:
  - The most important variable is the heat flux to which the specimen is exposed (the time of exposure is implicitly also important, since a certain minimum time is required at any heat flux for ignition)

T_{ig} values…

- Study found that T_{ig} 🕔 250°C (482ºF) for radiant autoignition if the heat flux is near the minimum flux at which the material will ignite.
- T_{ig} rises if heat flux is increased
- The presence of a pilot is irrelevant at low heat fluxes, since wood ignites at the surface (glowing ignition) and a pilot in the gas would have no effect.

The nature of ignition...

- Observations show that ignition at the minimum heat flux is always a glowing ignition.
- At slightly higher fluxes, ignition is a 2-stage sequence: glowing followed by flaming.
- Data show that T_{ig} rises rapidly with rising heat flux in this regime

T_{ig} for glowing ignition

- Theory
  - Theory of Baer & Ryan and Lengellé shows that T_{ig} is not a constant but rather increases with heat flux according to:

$$T_{ig} = \frac{E_s}{R}\left[\ln\left(\frac{B_s Q_s}{\alpha\,\dot{q}_e''}\right)\right]^{-1}$$

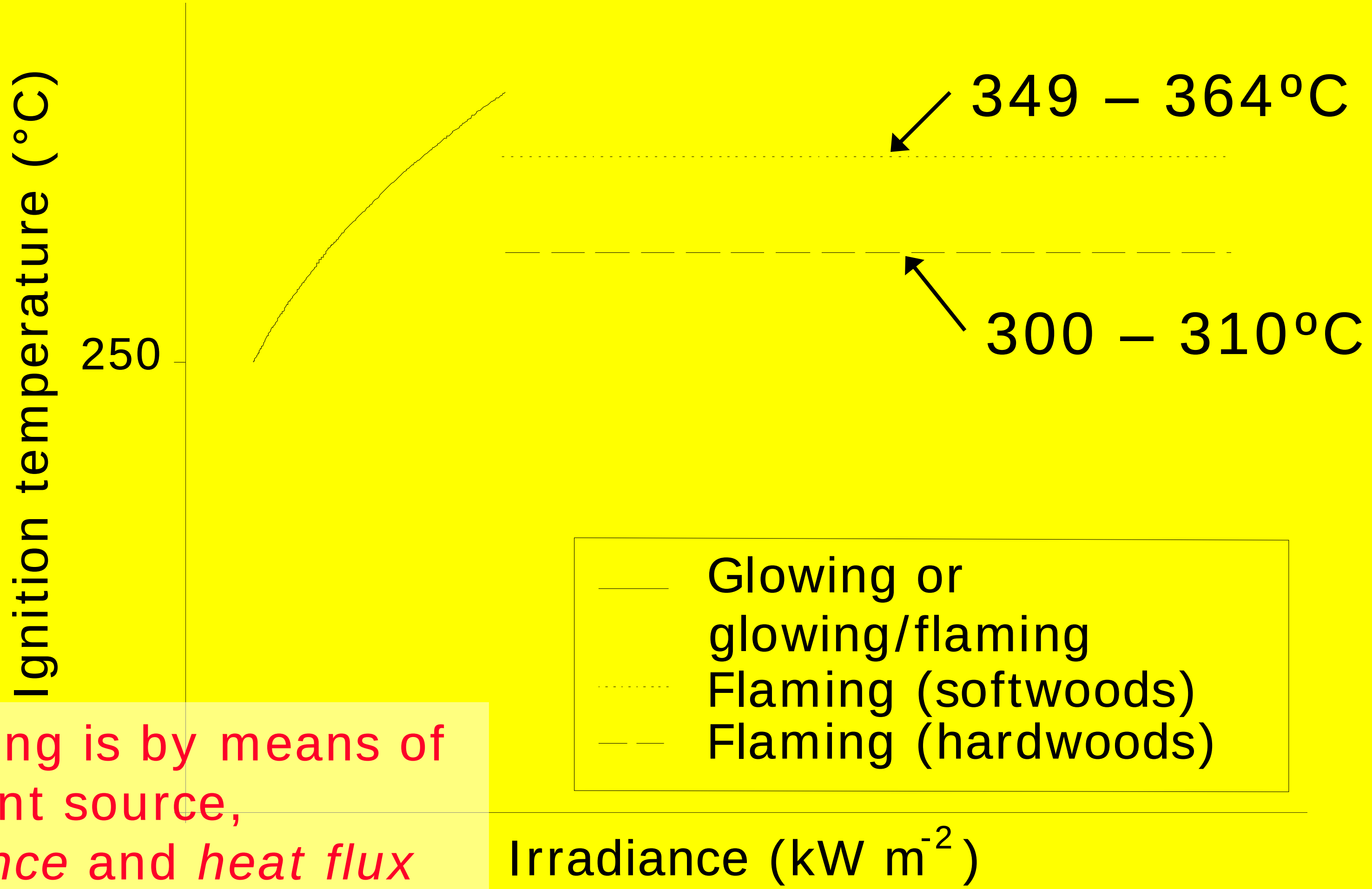
Regimes of external ignition for wood

- At lowest heat flux, ignition is always initially a glowing ignition
  - The combustion often, but not necessarily always, later becomes flaming (this is known as a 2-stage ignition)
- At higher heat fluxes, ignition begins directly in the flaming mode; there is no glowing step preceding it.

Heat flux values for the different modes

- Lowest value of heat flux for which ignition is possible is 4.3 kW/m^2
  - This is based on a single study and future studies may refine this value
- Upper limit for two-stage ignition:
  - 22 kW/m^2 under piloted conditions
  - 33 kW/m^2 under non-piloted (autoignition) conditions
  - These two values should be considered very approximate, since there have not been many reported experiments and they disagree quite a bit among themselves.

Piloted ignition T_{ig} summary

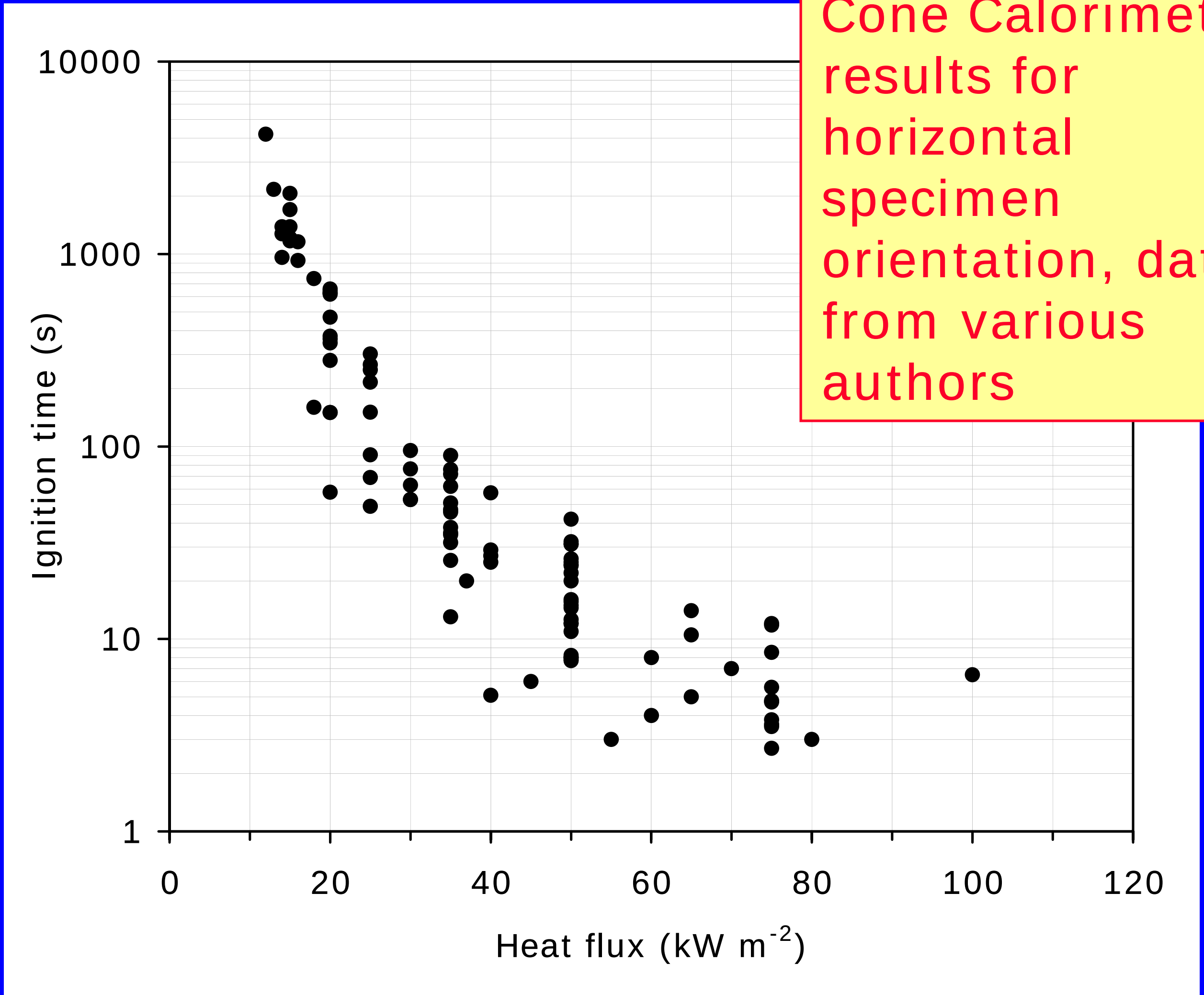


If heating is by means of a radiant source, *irradiance* and *heat flux* are used interchangeably

NFPA 921 information

- Even the latest edition (2004) gives **outdated**, incorrect information on wood's T_{ig}.
  - Sec. 5.3.2.4 says that autoignition temperature is 600°C (1112°F) if heating by radiation and 490°C (914°F) if heating by conduction.
  - These values are based on some ancient results cited in Drysdale's book and way too high, with regards to the minimum values we have just presented here.
  - In addition, Table 5.3.5 gives values and implies that they are generally valid—but they are **NOT** the minimum values and only pertain to **higher-heat-flux, flaming** ignitions.

Piloted ignition of wood: Time vs. heat flux



Cone Calorimeter results for horizontal specimen orientation, data from various authors

Published values of minimum heat flux needed for ignition of wood…

- **Autoignition**:
  - The published literature shows values of 20 - 100 kW/m^2 for the minimum heat flux
    - Reasons unclear why so much variation
  - These values are all way too high, since tests run were typically only 20 min, or less
    - In many practical cases, ignition can be from some source of heat which lasts for hours, not minutes
  - NBS study provided a 1-day exposure period and obtained ignitions at 4.3 kW/m^2, which took 4 - 5 hours.

…Published values of minimum heat flux needed for ignition of wood

- **Piloted ignition**
  - Many handbooks list a value 12.5 kW/m^2
  - Spearpoint recently measured 7-8 kW/m^2
  - But minimum flux for piloted ignition cannot be higher than for autoignition (unless the pilot is so bad it actually interferes with ignition!)
  - Also, as indicated above, the presence of a pilot is irrelevant at the lowest fluxes
- Therefore, the minimum heat flux for piloted ignition is also approximately 4.3 kW/m^2.

Self-heating

- Self-heating occurs due to chemical reactions. Materials which are chemically “inert” cannot undergo self-heating. *Example of an “inert” material: glass.*
- But note that “inertness” depends on circumstances. Iron is inert in a normal room fire, but can self-heat to ignition if in the form of freshly-made, fine powder.

Self-heating: more examples

- Self-heating of iron powders is rarely encountered by fire investigators
- Most common example: linseed-oil soaked rags
- Other common examples: haystacks, compost heaps

Requirements for ignition due to self-heating

- Needed prerequisites:
  - chemically reactive material (fuel)
  - adequate availability of oxygen (usually means fuel must be porous)
  - big enough size of heap, pile, etc.
  - time for reactions to occur.

Why isn’t everything spontaneously combusting all over the place?

- The world around us is very full of organic materials which can react exothermically with oxygen
- Oxygen is generally present copiously in most environments
- Since no external ignition source is needed for spontaneous combustion, why isn’t everything spontaneously combusting?
  - Must consider the details of the chemistry.

Some definitions…

- **Self-heating**: “A rise in temperature in a material resulting from an exothermic reaction within the material.” (ISO Standard 13943)
- **Thermal runaway**: “Self-heating which rapidly accelerates to high temperatures.” (**Ignition Handbook**)
- **Spontaneous combustion**: “Visible smoldering or flaming caused by thermal runaway.” (**Ignition Handbook**)

…Some definitions…

- **Spontaneous ignition**: sometimes used as a synonym for **spontaneous combustion**. But this causes confusion, since externally-heated materials which ignite without the help of a pilot are also described as undergoing spontaneous ignition.

…Some definitions

- Best usage:
  - Avoid “spontaneous ignition”
  - Refer to substances which started burning due to self-heating as undergoing **spontaneous combustion**
  - Refer to substances which started burning due to external heating (without pilot) as undergoing **autoignition**.

The steps involved

(1) **Self-heating**

(2) Self-heating may or may not lead to **thermal runaway**. In most self-heating-prone materials encountered by the fire investigator, thermal runaway will manifest as *smoldering*.

(3) Thermal runaway may or may not lead to **spontaneous combustion**. If it does not lead to spontaneous combustion, the outcome will be a piece of material with a charred-out zone, but smoldering will stop by itself and flaming will not occur.

Application of the fire triangle

- The fire triangle states that a source of heat is needed.

- But in the case of self-heating materials, the source of heat is the chemical reactions occurring in the substance itself; no external heat source is *required*.

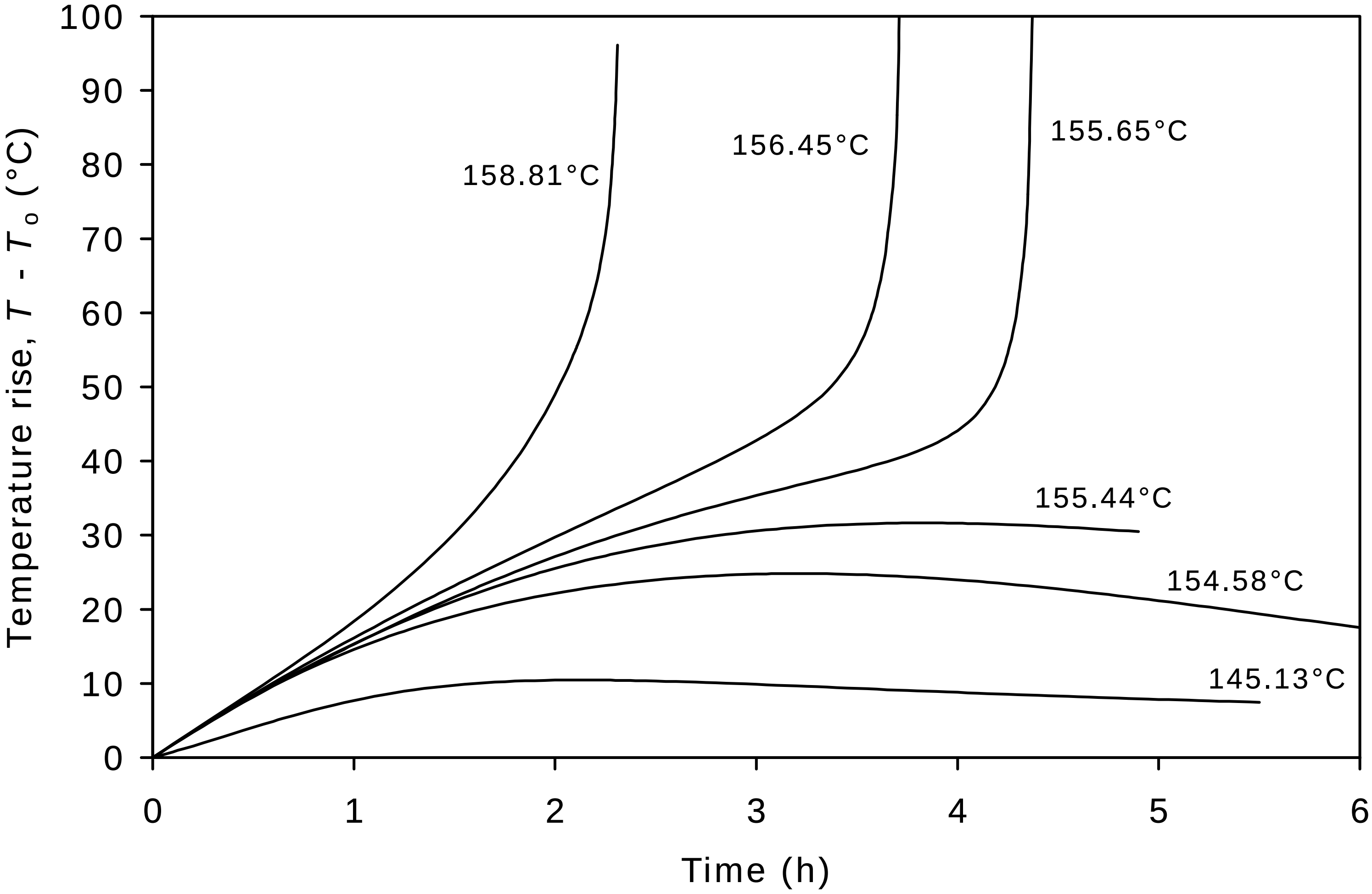
  - However, the self-heating process can be *aided* by the presence of an external source of heat (a hot object).

Quantitative aspects of self-heating

- The important variables:
  - Chemical reaction rate
  - Convective cooling
    - Temperature of environment
  - Size of object

Example of influence of ambient temperature

6-liter cylinders of wool held at various temperatures



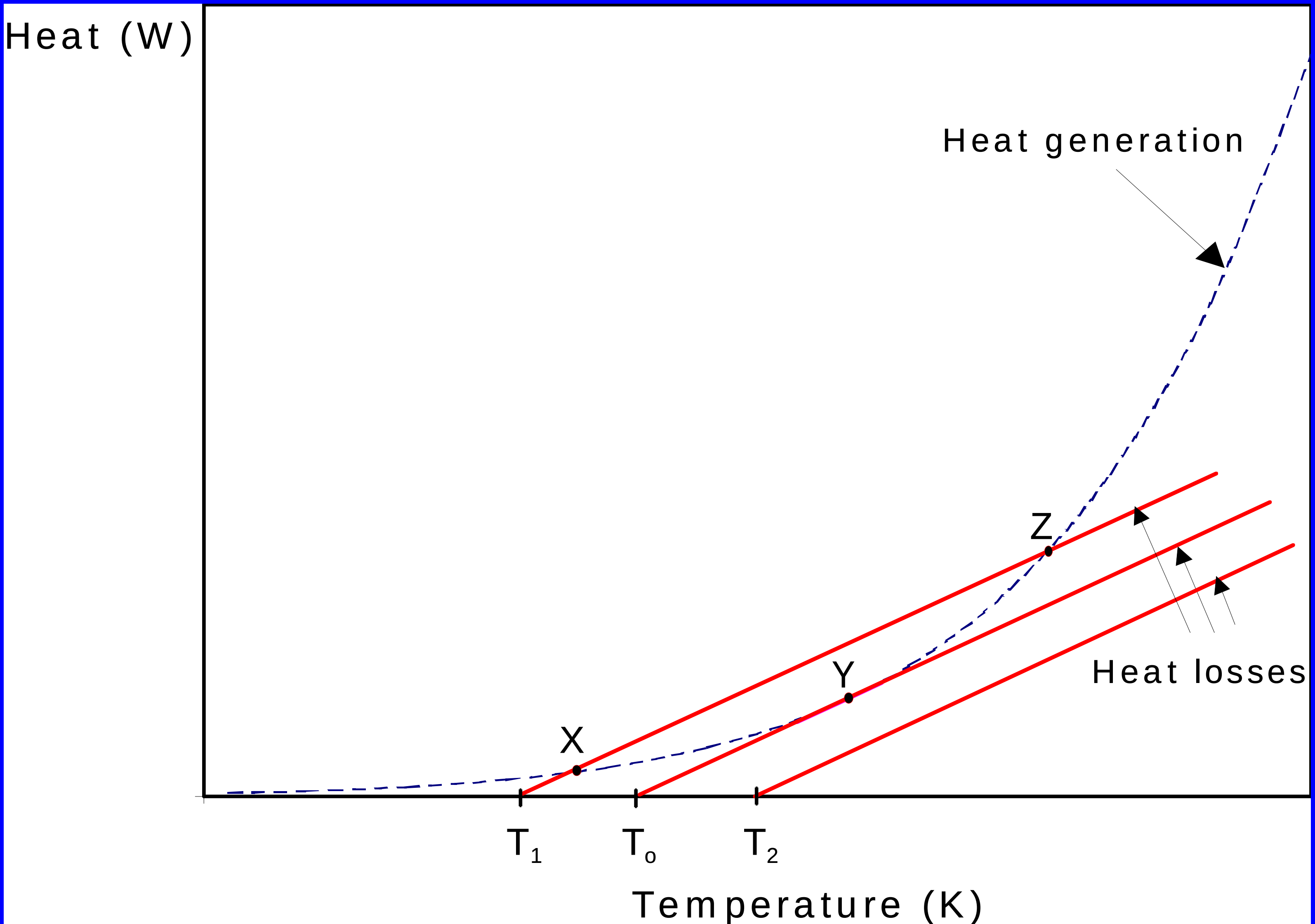
Theory of ignition due to self-heating

- First theory proposed by Russian researcher Nikolai Semenov in 1928. Theory was useful for analyzing chemical plant explosions, but was not sufficiently realistic to be applied to self-heating of porous solids.
- A theory that could be used to analyze porous solids was put forth in 1939 by Russian researcher David Frank-Kamenetskii (theory is often known as **F-K theory**)
- Important extensions to theory made by British research Philip Thomas during 1958-1961.

…Heating and cooling of porous solids…

- It is found experimentally that:
  - – Heat generation depends *exponentially* on temperature
  - – Heat losses depend *linearly* on temperature

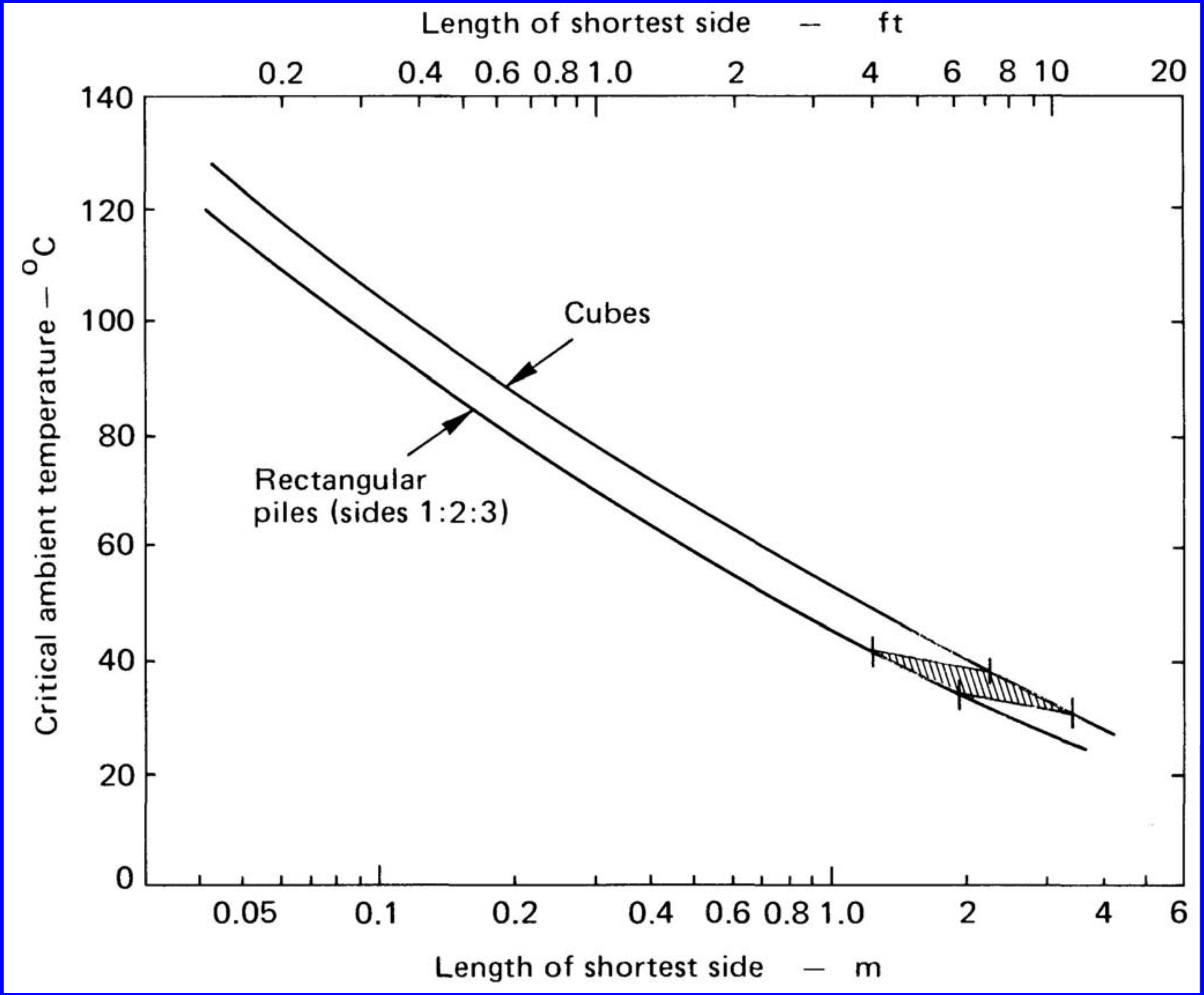
…Heating and cooling of porous solids



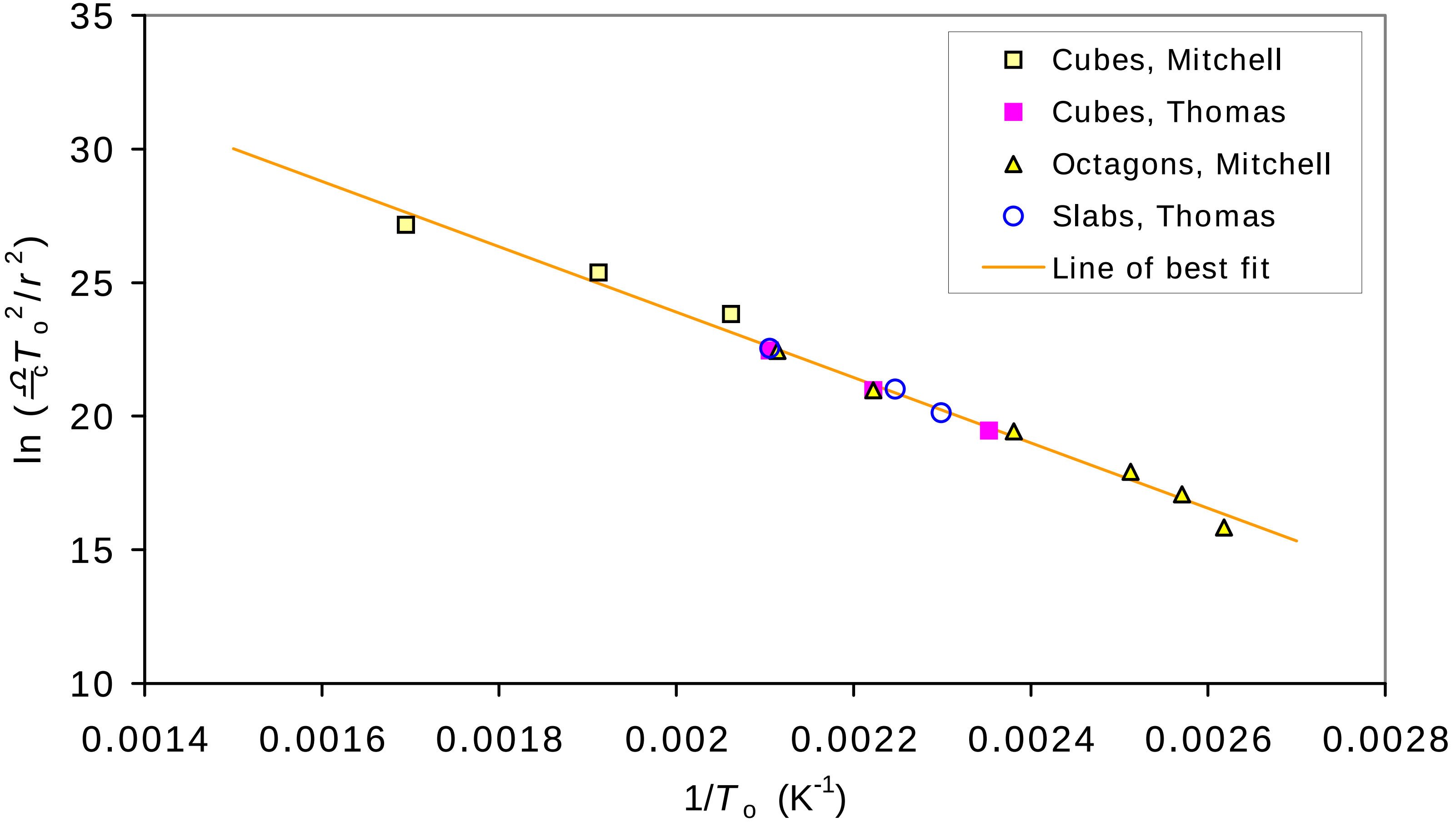
Using F-K theory

- F-K theory is normally used by making small-size tests in the laboratory, then extrapolating the results to the large-scale problem.
- Small-size tests in laboratory are usually oven-basket tests:
  - wire baskets of the material are prepared in various sizes, then the oven temperature needed to cause thermal runaway is determined
  - a graph is made of the results

Example case—Activated carbon self-heating in ships' holds



Data are normally presented by using transformed variables which linearize the curve—Example: wood fiberboard



Assumptions made in F-K theory...

- There is only 1 chemical reaction.
- Reaction is single-step only. None of the reaction products undergo further reactions.
- The reaction is described by the same reaction constants under all circumstances.
- As much oxygen as needed is always available.
- Thermophysical and thermochemical properties of materials are temperature-independent, fixed constants.

…Assumptions made in F-K theory

- Moisture has no effect on self-heating.
- No mass flow (of anything) is considered.
- The geometry is fixed and does not change during heating.
- The substance does not undergo physical changes, for example, cracking.
- Also important to note that the theory gives a *steady-state solution* only—a graph of temperature versus time is *not* produced.

F-K theory has been shown to be <u>in</u>applicable to:

- bagasse
- benzoyl peroxide
- calcium hypochlorite
- coal
- fertilizers
- haystacks
- liquid-soaked pipe insulation
- sodium dithionite
- synthetic dyestuffs (certain types)
- synthetic rubber.

Some reasons why F-K theory cannot successfully treat some substances

- Strong roles of oxygen and moisture flow
- Effects of phase change
- The problem time constants are so long that a full time-dependent solution must be sought, rather than being able to rely on steady-state results
- Biological heating by micro-organisms
- Multiple chemical reactions
- Large variations in thermal properties

MOST IMPORTANT CONCEPT

- A fixed, “handbook” ignition temperature is **NEVER** applicable to self-heating problems.
- The temperature at which self-heating substances will ignite is determined by the size of pile, among other factors.
- Most self-heating substances can reach ignition in an environment which is at room temperature (or lower), if a sufficiently large pile is assembled.

The problem of low-temperature, long-term ignitions of wood

- Reports started appearing in the literature around 1900 of ignitions from uninsulated steam pipes going through, or next to, wood structural members.

- Ignitions typically took 3 months to 15 years after initial steam pipe installation.

- Must know type of steam system installed to be able to discuss temperatures.

Steam systems

- Need to distinguish low-pressure from high-pressure steam systems.
- Definition of “low-pressure steam”: less than 2 atm (abs.) [14.7 psi gage]. Maximum temperature in low-pressure steam system: 120°C [250°F].
- High-pressure steam: over 2 atm (abs); over 120°C
- Low-pressure steam is commonly used in residential and commercial occupancies; high-pressure in industrial occupancies.

...The problem of low-temperature, long-term ignitions of wood...

- Since high-pressure steam lines can exceed 200°C, ignitions from high-pressure steam lines are not puzzling, since this is close to the 250ºC T_{ig} value for external heating; so self-heating would not even need to play a role.

- Ignitions from low-pressure steam lines (100 - 120°C, typically 105°C) do involve self-heating.

Case history studies...

- Mostly done in the earlier years of the 20th century
  - Bixel & Moore (1910)
  - Independence Inspection Bureau (1911)
  - NFPA (1925)
  - Virtala at VTT (1949)
  - Matson, Dufour, and Breen at UL (1959)
  - Östlin (1960)

…Case history studies:
Östlin (Swedish Fire Protection Assn.)…

Hot object	**Ignited**	**Est. peak temperature**	**Est. time**
insulated steam boiler return pipe	25 mm thick floor board	90-100ºC, rarely up to 120ºC	unknown
steam boiler return pipe	sawdust & shavings	70 - 100ºC	unknown
condensate water	insulation comprising cardboard + 12 mm wood	90ºC	unknown
high pressure steam pipe	wood scaffolding	200ºC	2 h
pickling tank	floor under tank	112ºC	1 yr
low pressure steam pipe	cardboard + mineral wool	106ºC	< 1 yr

...Case history studies...

- Early researchers rarely measured temperatures and rarely noted whether steam pipes were high- or low-pressure
- A few incidents are reported involving hot-water (not steam) pipes.
  - These are, by definition, at less than 100°C.
- Steam heat is less common today, so modern case reports involving steam pipes are more scarce.

...Case history studies..

- Modern cases often involve wood igniting under a boiler or furnace, where boiler/furnace was placed on sheet metal, below which is a wood platform.
  - Very hard to estimate temperatures for this situation.

Best-documented recent case…

- Occurred in an apartment house in Winnipeg, Canada on January 7, 2001.
- Was investigated by a competent, impartial authority—Manitoba Province Office of Fire Commissioner.
- Originated at a 1-¼" hot-water heating pipe, at the point where it passed through a hole cut in a wood floor assembly consisting of a 38.1 mm (1.5") wall plate on top of a 15.9 mm (5/8") OSB subfloor.
- The furnace was producing hot water at 88 – 93ºC [190 – 199ºF] and was found to be in proper working order.

Overall view of point of origin

Photo: Ken Swan

Close-up of point of origin

Photo: Ken Swan

Case with lowest-known temperature…

- Occurred in a single-family residence in Van Nuys, CA on February 4, 1972
- Point of origin was where a domestic hot-water pipe passed through a hole cut in a 2" x 4" wood header.
- To eliminate the possibility of vibration noise, the plumber (conscientiously!) hammered in a wood wedge into the annular space, since the pipe did not fully fill the hole drilled for it.

…Case with lowest-known temperature

- The residents had set the water heater discharge temperature at 77ºC (170ºF) since there was a large family and they had otherwise been running out of hot water.
- On the evening of the fire, numerous members of the family took showers prior to leaving for a party.
- Fire broke out a few hours afterwards.

Chemistry of wood oxidation…

- Oxidation in wood occurs at all temperatures, even at or below room temperature.
  - This can be demonstrated easily: Inspect the color of wood joists that have been in-place for several years and compare to the color of new ones. It will be seen that the new ones are nearly-white, while the older ones are deeply yellowed. This is due to chemical reaction going on, and the reaction is largely oxidation, although other reactions are also involved.

…Chemistry of wood oxidation…

- The wood joist sitting in normal temperature room air will discolor, but will not ever char or ignite.
- Raising the temperature slightly increases the rate of chemical reaction greatly—this is not a linear process.
- During short-term heating, wood has to be raised to about 288ºC (550ºF) to get charred.
- But if prolonged periods are involved, much lower temperatures suffice…

…Chemistry of wood oxidation…

- A study was done by McNaughton at the Forest Products Laboratory in 1945.
  - He exposed matchstick-sized pieces of wood to moderate temperatures for up to 3 years.

…McNaughton's results

Temperature	Time (days)	Condition
107°C	1050	light chocolate color
120°C	1235	brittle, dark-chocolate color
140°C	320	lost 45% of weight, became like charcoal
150°C	165	lost 65% of weight, became like charcoal

…Chemistry of wood oxidation…

- McNaughton’s results do NOT imply that putting wood into an environment below 120°C will not cause it to char.
- The 120°C value is pertinent to infinitesimally-thick samples.
- Oxidation and self-heating are strongly dependent on the size of the object, and a lower temperature suffices if the size is made larger.
- Wood studs, beams, joists, etc. are much larger than matchstick-sized.

Ignition of wood due to self-heating…

- If, in these cases on long-term, low-temperature heating, wood does not ignite simply due to external heating, then the process must involve self-heating.
- It is well-known that material of the same chemical composition as wood (sawdust, fiberboard) self-heats readily, and that big heaps of such material are dangerous.
- Wood is sometimes thought of as a hard substance without porosity.
  - This is untrue—wood is porous.
  - While virgin wood has low porosity, long-term heating **causes** porosity.

…Ignition of wood due to self-heating…

- Thus, the basic chemical prerequisites exist for ignition from self-heating.
- But the process **CANNOT** be analyzed by applying the simplistic F-K theory.
  - British researcher Philip Bowes attempted to do this and concluded that the F-K theory would suggest that structural wood members will not ignite from steam pipes running at less than 200ºC.

…Ignition of wood due to self-heating…

- The inapplicability of the F-K theory could readily be seen by considering the **time scale**. Computations with the F-K theory or lab tests on oven-cube samples of the sort used in conjunction with the theory show that if thermal runaway occurs, it occurs in only a few *days*.
- Actual case incidents of long-term, low-temperature ignition of wood members involve exposures of months, or more commonly, *years*.

…Ignition of wood due to self-heating…

- Why does the F-K theory not apply to long-term, low-temperature heating of wood members?
  - The process appears to be dominated by the effect of cracking. Char formed under conditions of restricted oxygen is highly reactive when later exposed to copious oxygen conditions. The cracking of char is a long-term process and one that has, thus far, proven to be resistant to efforts of theoreticians to develop equations for it.

A note on pyrolysis

- If a substance was pyrolyzed, it does NOT automatically mean it has become more easily ignitable.
- In most cases, a pyrolyzed substance is LESS easily ignitable than virgin material.
- It was shown in several research studies that if wood members are pre-charred (=pyrolyzed), they become more difficult to ignite from external heating.

Terms to be used…

- “Pyrolysis” does not <u>explain</u> anything about the long-term, low-temperature ignitions of wood.
  - For ignition to occur, obviously the material must get degraded (pyrolyzed), but this is a condition and not an explanation.
- “Pyrophoric carbon” is not a good term to use, simply because the definition of “pyrophoric” does not apply here.

…Terms to be used

- **Pyrophoric material**: “a liquid or solid that, even in small quantities and without an external ignition source, can ignite within 5 minutes after coming in contact with air when tested according to UN Manual of Tests and Criteria.” (US Dept. of Transportation)
  - Obviously, the 5-minute time scale does not apply here.
- It is best to describe these fires simply as ignition of wood due to “long-term, low-temperature heating”.

Research needed...

- At the present time, this phenomenon is adequately documented so that the temperature range in which it can occur is known. But a chemical/mathematical theory is not available which would allow predictive computations to be made. Thus, research would be desirable.
- A suitable scheme might be:
  - Conduct real-scale tests (e.g., actual wood members) under realistic test conditions. This means a mockup of a meter or so in size, with maybe a 150 mm [6 in] thick member being used. These members should not be inserted in an oven bodily, but, rather, the wood member should be heated the way it will in practice: by a hot metal pipe or duct.

…Research needed

- In view of the possible importance of thermal cycling, two types of tests should be run: ones with the pipe at a constant temperature, and ones with temperature cycling.
- A period of 3 years might be a suitable time during which the experiment should be left in place and let to run its course.
- A number of replicates must be run.

Truck Insurance v. MagneTek

Lessons to be learned by fire investigators

The Court decision

- The US Court of Appeals for the Tenth Circuit made a decision recently which revealed a distressing lack of understanding by the Court of the basic principles of fire science.
- I have not had an involvement in this case and do not have an opinion on the facts of that fire, nor on the quality of the fire investigation that was done.
- From my point of view, the problem is not that injustice may (or may not) have been done to certain parties, but that the Court put into the record concepts of science which are grossly wrong.

Main problems with the decision

- Denies that a material can ignite due to self-heating.

- Postulates that a hot object cannot ignite an ignitable substance if its temperature is below the published “ignition temperature” for this substance.

- Considers that “science” consists only of theories or equations, and refuses to acknowledge that “science” also includes phenomena where there is a systematic body of empirical knowledge, but no quantitative theory or equations.

Details

- The Court rejected the plaintiffs' claims because it concluded that the plaintiffs were presenting what it called a "pyrolysis theory."
- The Court stated that it found "the long-term, low-temperature ignition theory" to be "unreliable" and, therefore, excludable under *Daubert*.
- It concluded that "Wood normally will not catch fire until exposed to a heat source of nearly 400º[F]" and stated that ignition cannot occur if an object does not exist nearby which is at this temperature, or higher.

Understanding the issues…

- “Pyrolysis theory”
  - As explained here earlier, pyrolysis is a **definition**, not a theory. It is a fact which is not disputed by any known scientist that wood undergoes pyrolysis when heated.
  - Furthermore, not only is this definition essentially universally subscribed to be all fire scientists, but a definition cannot be wrong! (It can be unhelpful, or it can be one which is only held by an ignorant person, but it cannot be wrong, because it does not describe the physical universe, and only establishes how a person uses a certain word).

…Understanding the issues…

- "The long-term, low-temperature ignition theory"
  - This is not a theory! It is scientifically valid, but not because it is a theory. Rather, long-term, low-temperature ignitions of wood are reliably documented as empirical scientific findings.
  - Reliable scientists or scientific organizations who have documented this phenomenon include not only yours truly, but also:
    - ♦Prof. Ira Woolson (Columbia University)
    - ♦Voitto Virtala (Technical Research Center of Finland)
    - ♦Underwriters Laboratories
    - ♦Swedish Fire Protection Association

…Understanding the issues…

- “Wood normally will not catch fire until exposed to a heat source of nearly 400ºF”
  - This is true for **external** ignitions
  - For ignition due to long-term, low-temperature self-heating, a temperature of 77ºC (170ºF) has been demonstrated to be sufficient.

…Understanding the issues

- A hot object must be at a temperature at least equal to the ignition temperature of the ignitable substance, if it is to ignite that substance (the Court did not summarize it in an easily-quotable phrase, but that is what it evidently meant).
  - This is patently untrue
  - No hot object of any sort needs to be inserted into a haystack for it to catch fire due to self-heating.

What should investigators do in the future?...

- Refrain from using the word “theory” in connection with long-term, low-temperature heating of wood
- Explain to the Court that ignition can be of two types: due to external heating, or due to self-heating
- Explain that a concept of a fixed, handbook temperature does not apply to self-heating substances.
- Explain that long-term, low-temperature ignition of wood has been reliably documented by scientists—there is nothing “speculative” about it.

…What should investigators do in the future?

- Explain that valid, scientific knowledge can be of two types:

  (1) A systematic collection of data which indicates certain general truths.

  (2) A theory which explains “why” something occurs and is accompanied by an equation(s) to calculate it.

  (Theories are also possible where an equation has not been successfully produced, but the details of the phenomenon have been understood qualitatively.)

Summary from the point of view of product design/installation defects

- For short-term (a few hours or less) heating:
  - Hot objects must be kept below 250ºC, decreased by a suitable safety factor
  - Heat fluxes must be kept below 4.3 kW/m^2, decreased by a suitable safety factor
- For long-term (months, years) heating, including heat sources which are cyclically turned off:
  - Hot objects must be kept below 77ºC, decreased by a suitable safety factor
  - Heat fluxes, per se, have not been specifically studied, but in view of above, must obviously be kept below 4.3 kW/m^2.

Note concerning the literature…

- The fact that designers and installers must keep objects next to wood surfaces below 77ºC is not a new finding of this author.
- Already in 1959 UL published this recommendation:

  “As a limitation on the temperature to which wood may be heated for long periods of time from a standpoint of fire prevention, many authorities indicate that 90ºF above room temperature (approximately 80ºF) normally prevailing in habitable spaces is a safe maximum and one which incorporates a reasonable margin of safety.”

…Note

- Since 80 + 90 = 170ºF, the temperature cited in the 1959 UL recommendation is identical to the one established in my work.
- But there is an important difference in that, in my study, the 77ºC value has a zero safety factor, whereas the UL value of 77ºC, based on much earlier research, was intended to include some positive, but unspecified, safety factor.

Reference: Matson, A. F., Dufour, R. E., and Breen, J. F., Survey of Available Information on Ignition of Wood Exposed to Moderately Elevated Temperatures, Part II of “Performance of Type B Gas Vents for Gas-Fired Appliances” (*Bulletin of Research* No. 51), Underwriters’ Laboratories, Inc., Chicago (1959).

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