DEPARTMENT OF
PRIMARY INDUSTRIES

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Haystack Fires (Spontaneous combustion)

Haystack fires have a range of causes such as lightning strikes, sparks from equipment and machinery and deliberately or accidentally started. However, many haystack fires self-ignite for no apparent reason. This is called spontaneous combustion and is the leading cause of haystack fires in Victoria.
Spontaneous combustion can occur in a stack of any size or in a single bale which is too moist.

Causes of spontaneous combustion

The heating of hay is the result of a complex chain of biological events and chemical reactions. Heating and potentially spontaneous combustion can be caused by excess exterior moisture or insufficiently cured internal plant moisture (plant sap).

Excess external moisture can be caused by rain, dew, flood water, etc. trapped inside hay bales at baling or externally from a rainfall event after baling. Heating also often occurs when the plants are baled too "green" due to the plant's internal moisture or sap content being too high.

Either reason, or a combination of both, allows microbial activity or plant respiration and enzyme activity to continue, increasing as more moisture and heat is generated by this activity. Spontaneous combustion is the result of hay heating to such high temperatures, in specific environmental conditions that the material ignites without an outside source of ignition

For excessive heating to occur the hay will contain moisture in excess of what is considered satisfactory to store hay safely. This excess moisture leads to increased microbial activity and plant respiration. Both of these processes in the presence of the moisture and oxygen (O2), causes the following reaction to occur.

Moist hay in the presence of oxygen produces carbon dioxide and water and HEAT

i.e. **Wet Hay + $O_2 \longrightarrow CO_2 + H_2O$ + HEAT**

The impact of curing on hay

Ideally, well cured hay is dried externally (free moisture) and internally (plant sap or juices) to such an extent that only minimal or negligible heating will occur (Table 1). However, hay baled at 10 – 12% moisture will not heat at all, being so dry, but dry matter (and nutritive) losses will occur due to shattering of this extremely dry material. To avoid this most hay is baled at slightly higher moisture contents, the level dependent on bale type.

Most hay baled at moisture contents above 15% will experience some heating in the first 2 - 3 weeks after baling. Moisture or dampness is also produced simultaneously as a result of the heating and is commonly referred to as "sweating." This heating is due to very low rates of plant respiration and enzyme and microbial activity by moulds, yeasts and aerobic bacteria.

Even relatively dry hay (15 – 20% moisture content, depending on bale type) will heat enough to cause some dry matter (DM) losses (4 – 5%) but not enough to reduce hay quality. This heating causes the evaporation of the residual moisture in the hay which dissipates the released heat into the air. Eventually the hay will reach its own equilibrium moisture content, approximately 15% moisture, depending on climate.

Rule of Thumb to estimate DM loss

Yield loss of round bale hay is that 1% of original yield will be lost for each 1% moisture that is lost as stored hay reaches its equilibrium storage moisture. For example, when hay is baled at 22% moisture which then dries to 14% moisture, dry matter loss will be approximately 8%.

Excess moisture in hay arises from:

- Moisture trapped inside the bale
- Exterior moisture on bales after baling
- Internal plant sap moisture

Moisture trapped inside the bale

The most common cause of hay heating and/or haystack fires is excess surface or "free" moisture present on hay windrows at baling. This moisture may arise from excess dew overnight, sections of the windrows not being cured enough such as the bottoms of windrows, or a rain-affected windrow insufficiently dried before baling. Plant respiration is almost negligible when hay is well cured. However excess free moisture or insufficient curing may provide enough moisture to allow plant respiration to recommence, or continue at a higher rate if not well cured at baling. This moisture will definitely cause bacteria and mould activity to occur which will generate heat and eventual evaporation of this moisture.

Despite the remainder of the forage being well cured and safe to bale, a single bale or few bales may be unsafe to bale and can potentially cause a haystack fire. Over-wet material can be due to "hard-to-dry" capeweed, low lying or shaded areas, heavy outside windrow, etc.

Exterior moisture on bales after baling

Heating can also occur due to excess moisture build-up on the outsides of hay bales. Heavy rains after baling before the hay is covered can soak into bale exteriors for several centimetres. Condensation can accumulate rapidly on the underside of tarps used to cover freshly baled hay and could cause the same problem, particularly after heavy rainfalls. If these bales are stacked before they are sufficiently "re-dried" then the upper bales will trap evaporating moisture and generate heat as a result of bacteria and mould activity.

A leaking roof or spout which allows rainfall to seep down between bales of hay can also lead to heating hay and possibly spontaneous combustion.

Another source of exterior moisture is flood water which can wet the bottom layers of bales in a shed or outside stack.

Internal plant sap moisture

Heating can also occur when the plants are not "cured" enough (i.e. too green) resulting in their internal cell moisture being too high at baling. This is referred to as "sap" moisture and is simply the moisture in the plant cells which also contains the soluble sugars and proteins. The plants are still alive although much less so than when freshly mown.

Heating also often occurs as a result of both surface and sap moisture.

The more moisture present on or in the hay under the right circumstances, the greater will be the amount of plant respiration and microbial activity and greater the amount of heat and moisture generated. This increased heat and moisture further increases microbial activity resulting in ever increasing heat and more moisture. This moisture migrates by capillary or wicking action into surrounding drier material to begin the process anew in that area.

However, at any stage during this heating process the heating may decline without reaching critical levels.

Steps to spontaneous combustion

Figure 1 shows the causative agents for the heating and possible spontaneous combustion of hay stored at high moisture content.

Initially, plant respiration (enzyme activity), mould (fungi) and bacterial activity generate heat in stored damp hay. As temperatures rise to 43 – 66°C, heat resistant (thermophilic) bacteria grow, driving the temperature higher. Microbes die once temperatures reach about 70°C but then exothermic chemical reactions (oxidation) occur which can push temperatures up to 110 - 140°C.

Temperatures can increase rapidly from this stage and it is thought that spontaneous combustion can occur when internal bale temperatures reach about 170°C.

Normally spontaneous combustion does not begin in the middle of most stacks because a lower concentration of oxygen in the stack centre may limit temperature increase making spontaneous combustion less likely. Hence, combustion more commonly occurs towards the outside of the stack where oxygen is more prevalent.

However, in extreme cases, spontaneous combustion may occur in the stack centre as a result of temperatures reaching about 280°C.

Hay is very dry once temperatures reach about 100°C. Since the thermal conductivity of dry hay is much less than that of damp hay, temperatures escalate rapidly within the stack from this stage onwards as heat transfer via evaporating moisture to outside air is much less effective.

Signs of heating hay

Symptoms that indicate a haystack is heating are:

- Heat of bales
- Steam rising from the stack
- Unusual odours (e.g. pipe tobacco, caramel, burning, musty)
- Moisture build-up on rafters or roofing iron
- Corrosion on underside of tin roof
- Sometimes slumping of an area of bales

Actions to take if a haystack heats excessively

Haystacks should be monitored for heating within days of stacking. If it does heat then monitoring should continue until heating subsides. Spontaneous combustion occurs about 4 – 14 weeks after baling normally but can occur earlier or up to four months later on some occasions. If the stack heats to excessive levels action is necessary to prevent the possibility of spontaneous combustion.

Factors contributing to the extent of heating and that can influence the time to spontaneous combustion are:

- Moisture content and bale type
- Bale density
- Environmental factors
- Storage conditions

Moisture content and bale type

Large rectangular bales, due to their very high density that restricts heat dissipation, are the most prone to heating and spontaneous combustion. Large round bales due to their large volume and dense nature, although less dense than the large rectangular bales, are the next prone. Small rectangular bales are the least vulnerable. However, heating and spontaneous combustion can occur in all bale types in the right conditions.

Table 1 indicates the current recommended moisture contents at which to bale each bale type safely.

Table 1. Recommended moisture contents (%) for safe storage of various bale types

Bale type	Moisture content range (%)
Small rectangular bales	16 – 18
Round bales (Soft centre)	14 – 16
Round bales (Hard centre)	13 - 15
Large rectangular bales	12 -14
Export Hay	Under 12

Hay with a moisture content slightly above the recommended levels will usually heat to some extent, then eventually cool to the ambient (surrounding air) temperature. The temperature will rise substantially if hay is baled with moisture contents well above (> 3%) the suggested levels, particularly the large rectangular and round bales. How much heating will occur is dependent on the factors mentioned earlier.

Lucerne and vetch may be baled at slightly higher moisture contents (+1 – 2% moisture) than those recommended in Table 1 because these plants have lower plant sugar contents than grasses type crops and cereals.

Often there has to be a compromise between the risk of baling at a higher than optimal moisture and further damage by rain on the cut crop. Heating will be likely to damage the hay more than the rain. Recent experience in drought affected cereal hay suggests that high sugar content of these hays makes them particularly susceptible to spontaneous combustion so baling at the lower end of the range is essential.

Density

Large rectangular bales are much denser than round bales which, in turn, are much denser than the small rectangular bales. Large round bales also have a large volume to surface area compared to the other two types. The order of heating and danger of spontaneous combustion is greatest with the large rectangular bales, followed by the large rounds, then the small rectangular bales. Hard-centred round bales (Figure 2) are more prone to heating than soft-centred round bales.

Figure 2. Hard centre of round bale has been extremely hot

Environmental factors

Environmental factors such as relative humidity (RH), ambient temperature and air movement can interact and compound the issue of hay heating. At any temperature hay will need much longer to dry at higher RH than at a lower RH. Obviously rain is not good.

Air flow over a stack aids in the removal of evaporated moisture and dissipated heat which reduces the build-up of heat and relative humidity around the stack.

Incorrect use of hay moisture meters

Hand held moisture meters are a tool only, a dough guide at best, to help ascertain the suitability of material for baling. The meter must be correctly calibrated before use and the correct technique of handling the meter itself are crucial. Equally important, the samples being tested must be representative of the material to be baled. This requires sampling along windrows and throughout its depth, being repeated over the paddock. Suspect areas, such as shaded or low lying sections need careful attention.

Any one of the above factors not being correctly managed can lead to errors in the readings being inaccurate by several per cent. Experience by operators in baling different crops in various weather conditions and knowing the foibles with individual moisture meters are invaluable.

Close examination of the hay by stripping the stems to look for moisture, or close examination of the knots of cereal hay will give good indications of the extent of curing. Well cured hay will have no sign of sappy tissue. Hay that is well cured but has been wet by rain of dew can be assessed by grasping a bundle in two places and twisting with a cranking motion. This well cured but externally wetted hay bundle should break in 2-4 twists.

There is some question over the accuracy of hay moisture meters in these extreme conditions such as not being able to measure sap moisture. Heating bales, due to the processes explained earlier, cause a continuing build up of moisture in the bale for some time in storage. The higher the moisture content in hay, the less accurate are most hay moisture meters.

Meters can be checked by taking a number of core samples. The sample will need to be collected from where the tip of the probe measures and be immediately sealed to prevent loss. Accurate weighing and drying at 70° C for 24 hours and reweighing will give moisture contents accurate to within approximately one per cent. A microwave oven can also be used to assess moisture content and is accurate to within ± 1 – 3%, if done correctly (See Agriculture Note AG1239: *Dry matter content of conserved forages: Measurement of dry matter content.*

Storage conditions

The larger the stack and the tighter it is stacked, the less opportunity there is for heat to escape. Loosely, but safely stacked bales enhance the air flow greatly thereby allowing generated moisture and heat to escape.

If "wet" hay is covered by dry hay, heat loss will be greatly restricted. If shed space is at a premium, and there are not too many wet bales, a single layer could be placed above the known dry hay but must be carefully monitored. Ideally these should be stored separately elsewhere.

Monitoring heat build-up in stacks

Once a stack is known to be heating, it should be monitored regularly. To date there has been no fool proof method for monitoring heat build-up in stacks. Technology may be available in the near future but is either untested, undeveloped for this purpose or may be too expensive. Such technologies are radar, thermal imagery, thermal couplings with data-loggers, etc.

Two commonly used methods to monitor heating are:

- Crowbar method
- Probe and Thermometer

Crowbar method

Push a crow-bar well into the stack, leave it for approximately two hours, then extract it and feel it with your hands. This needs to be done in several locations in the stack, preferably near the top because heat rises.

Table 2 Temperature interpretation using a crowbar

Temperature (^{0}C)	Interpretation
< 50	*Can handle bar without discomfort* Check temperature daily
50 - 60	*Can only handle bar for short time* Check temperature twice daily Remove machinery from shed
60 - 70	*Can touch bar only briefly* Check temperature every 2 - 4 hours Move hay to improve air flow
>70	**Bar is too hot to hold** Potential for fire. Call Fire brigade immediately. Avoid walking on top of haystack

A problem with this method is that the bar can only be pushed in to shallow depths and the problem may be much further into the stack. This technique also requires a couple of hours for the crowbar to heat before handling it. Despite these inadequacies, this method is better than nothing and is often successful to alert the hay owner to a heating problem.

Probe and Thermometer

Use a pipe of 2.5 – 3 m length, approx. 20 mm diameter, flattened on one end and drill 2 – 3 mm diameter holes about 75 mm above the flattened end. This length may be difficult to use in skillion roofed (no gable) sheds but the longer the probe, the better the heat indication deeper into the stack.

Drive the flattened end into the stack and lower a small thermometer to the end of the probe using light wire (string may burn/break). Retrieve thermometer after about 15 minutes. Refer to Table 2.

However, if the stack is near ignition point when inserting this probe for the first time, be very careful as this action may now allow air into the inner air-depleted section of the stack. It may suddenly catch fire.

What to do if the stack is too hot

Be very wary of walking across the top of a suspected hot haystack. If walking across the top of a very hot stack is necessary, place long wide planks, plywood sheets or a ladder across the top of the stack. Have a safety harness attached to a rope held by an observer nearby to react to an emergency.

The stack may be air deficient in the centre and so hot that bales may have become charred and much less dense. The stack can collapse inwards with the extra weight (you) on top. The sudden inrush of air to these charred bales will then be highly likely result in spontaneous combustion and severe consequences.

For the same reason, if an extremely hot stack is being pulled apart to allow it to cool down, it may suddenly catch alight as bales are removed by allowing air to enter the hot spot. Always be careful when removing bales and always have a fire cart or local fire brigade on hand.

Potential causes of increased proportion of haystack fires during droughts

The frequency of haystack fires appears to be higher than normal in periods of drought. In the 2006/07 drought, and 2007/08 extended dry period, a high proportion of these haystack fires were from cereal crops and/or large square hay bales. Spontaneous combustion was also sometimes occurring several months after baling, not normally common.

There may be several explanations for this and some alternative theories have been put forward as possible causes.

In periods of drought, the demand for fodder is very high and can be in very short supply along most of the entire eastern and south eastern states. This results in some material being baled before it was properly cured due to pressure to "get the job done" and be transported to areas of need. Another reason could have been new and inexperienced contractors with inadequate practical experience in handling and curing hay were caught out in a time when even some very experienced operators baled hay that caught fire.

A high proportion of increased frequency of haystack fires in droughts is from crops not normally baled, such as immature/failed cereal crops and canola hay (and silage). These require extra time to cure due to their extremely thick stems (canola) and immature heads in the vegetative boot stage of the cereal crops. Hay in both these situations is very difficult to cure satisfactorily.

The risk of uneven or insufficient curing is increased when using very wide (>10 m) windrowers to cut drought affected canola and cereal crops. Often two passes (>20 m) are put into the one windrow. Sometimes there is no follow-up with a conditioning pass. Even when conditioned, the same windrows may not have been managed correctly to ensure an even curing throughout the whole depth of windrow. This may result in some bottoms of windrows not being "turned over" at all.

It seems likely that the increase in the number of haystack fires in droughts is that the "failed", usually immature cereal crops, not having gone to head, would still contain very high soluble sugar contents in the plant's immature heads, top leaves and stems. The immature heads are often still in the boot inside the leaf sheath and would require much extra time to cure satisfactorily as would the extra moisture in the lower stem nodes or "knots."

These sugars convert to starch during the grain formation stage in a normal year and once harvested as grain, leaves a sugar depleted almost inert stubble, which even if rained upon, may become mouldy over time but unlikely to spontaneously combust.

It seems also that plants in drought stress produce an extra thick waxy layer on the leaves and stems to help conserve plant moisture. This would also reduce the rate of curing.

It is also possible that some crops, even though they had commenced heading, suffered a severe dry spell and the heads died. Follow-up rains resulted in an increased moisture build-up in the stems and nodes.

To avoid spontaneous combustion hay must be well cured and baled at or below the recommended moisture contents (Table 1), so if the above conditions are thought to be present be extra careful.

Protecting other assets

There are some simple steps that can be undertaken to minimise losses from fires not started by spontaneous combustion if they do occur.

- If practical, position haystacks in a number of different locations around the property so that only some of the hay is lost if a fire occurs;
- Locate haystacks away from key assets, such as buildings and powerlines;
- Locate haystacks away from possible sources of ignition, such as roadsides and vegetation;
- Create and maintain fire breaks around haystacks to reduce the likelihood of both hay fires escaping into the surrounding area and fires on the property igniting the stored hay; and
- Store vehicles, machinery and equipment well away from haystacks.

Further information

Further information on farm fire safety and management can be found in CFA's On the Land: Agricultural Fire Management Guidelines (CFA 2007) available on the CFA website (*www.cfa.vic.gov.au/business/farms*) or by calling (03) 9262 8444.

Agriculture Note AG1357: What happens to hay when it heats

Acknowledgements

This Agnote and *AG1357What Happens to Hay when it Heats?* replaces Agnote *AG0206 What Happens When Hay Heats?* by Keith Simmons and Hedley Simpendorfer ,December 1983. It was reviewed by Frank Mickan November 1999.

This Agnote was developed by Frank Mickan, Farm Services Victoria/Dairy, Ellinbank . October 2008

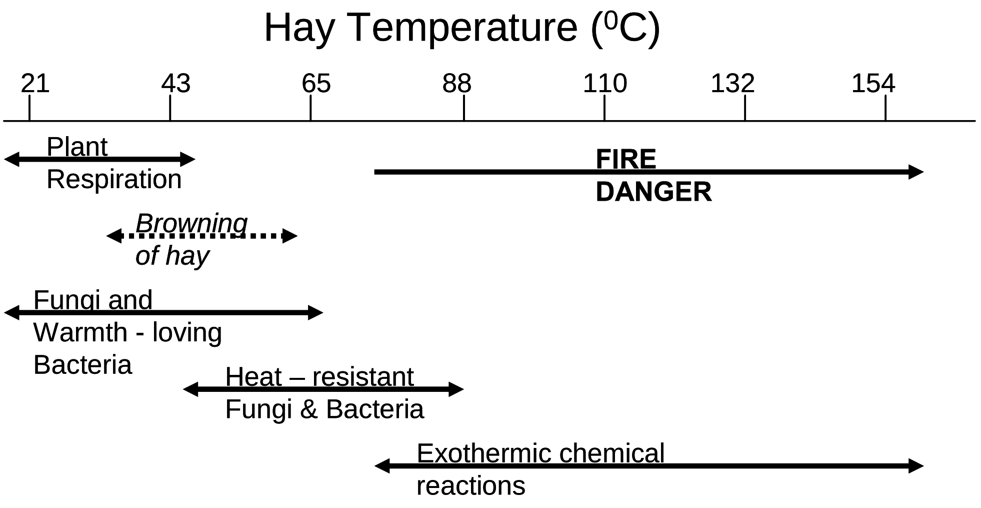

Figure 1: Causes of heating and Spontaneous Combustion of Hay. *Source: Sheaffer and Martin (1979)*

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