

The Spontaneous Combustion of Hay

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The mechanism of spontaneous combustion of stored hay is reviewed. Simultaneous changes in the chemical composition are outlined, which coupled with a microscopic examination, can be applied to diagnose the cause of a rick fire.

There is considerable paucity of information relating to the spontaneous combustion of hay. From time to time papers have appeared but conclusions are not usually final.

An effort has been made here to collect together the scattered information and to examine past work together with experience gained from hay samples of known history, to try to place knowledge on a firm basis and enable a more certain diagnosis of unknown samples to be made.

Hay when freshly cut is green and has a high moisture content. The mow is allowed to dry by exposure during which time the moisture is reduced from about 75 to 20 per cent. or less. At the same time as this is occurring, the chlorophyll is decomposing and brown decomposition pigments are seen. The dextrose content of properly treated hay is at least 4–5 per cent. and it is this dextrose which is the main indicator of changes which occur and which lead to the final combustion.

After the hay is considered dry, it is ricked and then heating occurs; Bolton¹ divides the heating processes of hay into three distinct phases:—

(1) *Normal heating.* This occurs in 5 to 7 days and is mainly due to normal metabolism of the plant cells and includes respiration which is an exothermic reaction and supplies the energy required by the plant. This initial heating may involve temperatures up to 120° F at which temperature the plant cells are dead and there is no respiration. Most bacteria living on the plant flourish below this temperature, i.e. about 100° F, and are killed off before a temperature of 120° F is reached, but a few thermophylic bacteria still exist and multiply.

(2) *Secondary Heating.* The temperature continues to rise above 120° F after 7 to 10 days due to action of thermophylic bacteria. *Bacillus calefactor* flourishes up to about 155° F which is the temperature limit of this stage. It is during this period that the changes are initiated which may ultimately lead to the stack igniting.

(3) This stage is from 155° F up to ignition point. This is essentially chemical in nature and ends by the combustion of various gases produced during or as a result of changes initiated during stage (2).

Samples of hay are submitted for examination in all stages of combustion, often in such an advanced stage of incineration that normally it has not been possible to venture an opinion as to how the sample arrived at its condition.

The Fire Loss Assessor usually has the best chance of deciding the cause of a particular stack igniting, and the signs have been reviewed by Firth² and Minton.³ Chemical investigations have been carried out by Dodd⁴ and Firth⁵ and it is with these methods that we are mainly concerned here.

Dodd does not consider the evidence from a bacteriological examination of the sample to have much value, with which the author agrees. For the most part Dodd estimates the ethereal extract, the total acidity and the non-volatile acidity, both acidities being expressed as lactic acid, but in his paper he does not define at which point one has to deduce that spontaneous ignition may occur.

Firth states that the percentage of ether extract is not a reliable guide to spontaneous combustion and in view of the complex and variable nature of this extract, this opinion is not questioned. Firth investigated the nature of the acidity and indicated that it was mainly non-volatile and predominantly lactic acid.

The late Sir E. Cook as far back as 1904 made use of acidity determinations in a similar manner to Firth. Cook also determined dextrose and based his conclusions on the relationship between dextrose and the two acids—lactic and acetic. Commenting upon two samples from the same rick, Cook states: "The numbers . . . show that the products of fermentation (i.e. the acids) have largely increased, whilst the glucose which is the principal substance which undergoes fermentation has largely decreased." The figures for these samples were as follows:—

	(a)	(b)
Moisture	57.9	59.4
Glucose	1.25	1.49
Fixed acidity as lactic acid	3.38	2.35
Volatile acidity as acetic acid	0.38	0.29

Cook, in his proof of evidence in a particular case (Vallender, Tewkesbury, 1912) further states that he has had experience of a rick firing spontaneously

TABLE I
THE COMPOSITION OF SOUND HAY

Sample Number	Moisture <i>per cent.</i>	Volatile Acid as Acetic Acid <i>per cent.</i>	Fixed Acid as Lactic Acid <i>per cent.</i>	Dextrose <i>per cent.</i>
1	16.2	0.05	0.12	4.05
2	11.2	0.45	0.70	4.90
3	8.7	0.12	0.84	4.89
4	10.7	0.00	0.90	3.94
5	8.7	0.12	0.72	4.79

where the fixed acid is only about one half of the dextrose, but usually it is more than that figure and often greater than the dextrose remaining after fermentation.

The figures obtained by examination of samples of hay by Cook's method have been accumulated over the last 50 years and typical figures have been abstracted and are summarised in the tables.

Table II gives results of over 40 hays known to have fired spontaneously. These results were taken at random over the last 50 years.

TABLE II
COMPOSITION OF HAY WHICH HAS UNDERGONE SPONTANEOUS COMBUSTION

Sample No. Number	Moisture <i>per cent.</i>	Volatile Acid as Acetic Acid <i>per cent.</i>	Fixed Acid as Lactic Acid <i>per cent.</i>	Dextrose <i>per cent.</i>
1	12.6	0.24	2.61	1.65
2	11.2	0.78	1.71	1.88
3	12.4	0.00	2.88	0.77
4	60.3	0.30	1.26	1.00
5	57.9	0.38	3.38	1.25
6	59.4	0.29	2.35	1.49
7	9.1	0.25	0.92	3.41
8	26.0	0.78	0.99	0.62
9	32.9	2.58	0.99	1.74
10	40.4	3.86	2.14	3.65
11	18.9	0.36	0.81	1.08
12	15.5	1.20	2.52	1.72
13	57.9	0.84	1.17	1.60
14	7.4	1.02	1.71	1.61
15	12.3	2.76	3.33	3.60
16	59.7	1.20	1.53	3.21
17	39.7	2.16	2.16	3.44
18	21.6	2.58	3.15	5.48
19	43.6	0.30	2.34	1.17
20	60.1	0.06	0.90	2.45
21	12.9	0.96	3.06	1.63
22	4.9	0.06	0.18	1.22
23	38.8	0.60	2.10	2.70
24	62.0	0.06	0.14	0.50
25	38.4	1.26	2.17	3.17
26	18.8	0.36	3.15	2.63
27	36.9	0.06	0.63	1.29
28	9.0	0.30	4.41	1.97
29	4.5	0.24	3.15	1.22
30	7.2	0.18	3.24	2.54
31	10.0	0.84	3.06	2.40
32	12.3	0.42	5.13	3.31
33	9.6	0.24	5.31	2.67
34	7.2	0.40	3.40	1.80
35	5.1	1.32	1.89	1.72
36	10.0	0.66	0.54	0.12
37	10.9	0.18	2.16	2.78
38	46.0	0.36	1.80	1.27
39	13.7	0.90	3.06	3.35
40	31.2	0.54	1.80	1.49
41	39.2	2.16	2.16	3.44
42	16.7	1.62	3.69	2.85

Table III shows the results of a few samples of hay which were liable to burst into flames at any moment.

TABLE III
COMPOSITION OF HAY WHICH IS UNDERGOING FERMENTATION BUT WHICH
HAD NOT FIRED

Sample Number	Moisture <i>per cent.</i>	Volatile Acid as Acetic Acid <i>per cent.</i>	Fixed Acid as Lactic Acid <i>per cent.</i>	Dextrose <i>per cent.</i>
1	17.1	0.10	1.98	2.63
2	9.0	0.96	0.90	2.22
3	10.3	0.18	3.96	11.15
4	11.6	0.30	4.30	7.89
5	10.1	0.12	2.97	4.85
6	10.3	0.00	1.44	1.45
7	8.5	0.30	2.34	5.30
8	18.0	0.30	2.54	0.74

The tests are carried out on the hay as received and no attempt is made to dry the sample before analysis which would result in loss of volatile acid. Neither was any attempt made to calculate the results to dry matter as it is not possible to differentiate between water used in quenching a fire and the water normally present. Samples with a very high moisture content which have been subjected to the action of water used in quenching the fire, may show rather lower acidities, etc., due to the solvent action of the water and also due to the previous heat driving off some of the volatile acid.

Methods

Moisture. A weighed quantity of the cut and well-mixed sample is dried at 100° C, allowance being made for volatile constituents.

Volatile Acidity. 10 g of the sample are repeatedly extracted under reflux with boiling water. After extraction the extract is made up to a known volume and aliquots taken for the following determinations. The extract is then steam distilled and the distillate is titrated with decinormal NaOH using phenolphthalein as indicator. The volatile acidity is calculated as acetic acid.

"Fixed" Acidity. The residue after determination of the volatile acidity is titrated with decinormal NaOH using phenolphthalein as indicator and calculated as lactic acid.

Dextrose. A portion of the aqueous extract is treated with Fehling's solution, the precipitated cuprous oxide being weighed or the alternative titration method can be used.

No deductions can be made about the moisture content, but a good hay in stack has usually less than 20 per cent. moisture. More moisture than this does infer that damage has been done by the firehose. Table I gives five results which are of quite sound hay. Smith's figures⁶ confirm this.

A very high moisture content may mean less volatile and "fixed" acidities. This is due to leaching of the soluble matters with water from a fire hose.

In general it can be said that when the sum of the percentages of fixed and volatile acids are greater than the dextrose figure, then the hay has either burst into flames or the sample is liable to burst into flames at any time.

Earlier reference has been made to heating of stacks and the stages through which heated stacks pass. Association of this together with some experiments in elementary botany where a pupil carefully heats a grass blade and observes that there is change of cell contents, but no change of cell structure during ashing, leads to the idea that possibly there may be something to be gained by microscopic examination of samples of hay submitted for examination. Briefly the underlying theory is that when a piece of grass is carefully ashed, it is possible to see the cell structure, but when chemical action has occurred then, due to the presence of gaseous products the cell walls are very distorted as a process resembling low temperature carbonisation has occurred.

The method of applying this is to soak selected pieces of the hay in molten ester wax (British Drug Houses Ltd.). The pieces are selected as far as possible near to the nodes as this produces a little extra rigidity which is of use when section cutting. The ester wax is poured into a mould, allowed to solidify, trimmed and sections through the hay are cut on a microtome.

The sections are floated on warm water, mounted on a slide, the ester wax removed by warm dioxan and the residual section then mounted in Canada Balsam for microscopical examination. An equally good and cheaper alternative is to use pith as an aid to section cutting.

The appearance of sections of hay is as follows:—

Figure 1 shows a section of normal hay. Occasional bursting of cell walls is seen. This may be due to the changes occurring during drying.

Figure 2 shows hay which has been destroyed by external heating. In this it will be seen that the cells walls are blackened and may have burst, but the general structure remains, especially around the vascular system.

Figure 3 shows the results obtained by spontaneous combustion. The cell walls are more distorted and blackened, and many cells are seen to be full of tarry matter. (It is important not to soak the hay sample in dioxan for too long, otherwise this may be removed).

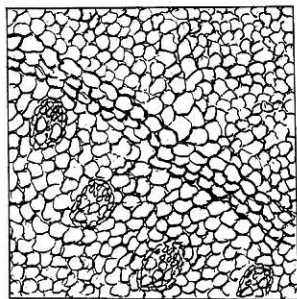


Fig. 1

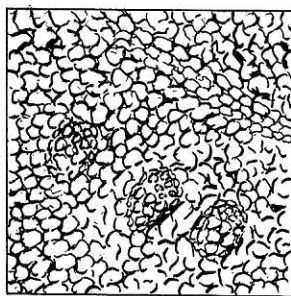


Fig. 2

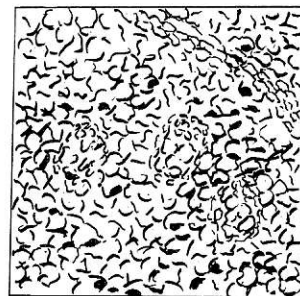


Fig. 3

The microscopic examination is of wider application than the chemical method alone and in the Author's opinion the two should be used to corroborate one another. It may be applied when the rick has been well damped by water and some of the soluble constituents may have been washed out, thus affecting the acid/dextrose ratio, upon which the chemical method depends.

It may also be applied when a rick has been practically burned out and insufficient hay, as such, remains for a chemical analysis. In this case, due to much of the hay having been burned as a result of a smaller portion firing spontaneously, it would be necessary to examine a considerable number of fragments. A preponderance of hay with cross-section resembling *Figure 2* would be observed, but some fragments with the characteristics shown in *Figure 3* might be found and would indicate the true cause of the fire.

The validity of the method is borne out by personal experience connected with a certain farm. The farmer made the first cut of hay during a wet June and left the hay to dry. For several days the hay in the field was observed often to be brown at night, reverting to green in the morning. It was ricked whilst still in a green condition, the rick being made unevenly and untidily. In the following September the rick fired and a sample was subsequently submitted for examination.

Chemical examination gave the following results:—

	per cent.
Volatile acid as acetic acid	0.54
Fixed acid as lactic acid	1.53
Dextrose	0.75

Microscopical examination confirmed the chemical tests and due to observing the conditions of making the hay and the rick, the correctness of the diagnosis of spontaneous combustion was supported.

A question sometimes raised after a stack has fired is that of the value of the residue. As a food, the residue may have a low value due to the loss of dextrose by fermentation, whilst protein would also be lost by carbonisation. On the other hand the mineral matter which is rich in potash would probably have increased proportionately and the salvage value would thus depend on its worth as a fertiliser.

Due to the present extension of the procedures of baling hay and silage making, examples of spontaneous combustion have decreased over recent years. Since some farmers continue to make hay in the traditional manner, it is considered of value to record the preceding experiences.

References

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