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The prevention of roof fires by the use of spark arresters

Frank Westen Peikert

Iowa State College

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THE PREVENTION OF ROOF FIRES BY THE USE OF SPARK ARRESTERs.

By

Frank W. Peikert.

A Thesis Submitted to the Graduate Faculty for the Degree of MASTER OF SCIENCE

major subject Farm Structures (Agricultural Engineering)

Iowa State College

1934.
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INTRODUCTION.

The annual rural fire loss for the United States has been placed by authoritative estimates at 275 million dollars which is approximately 60 per cent of the total fire loss. In addition to this enormous economic waste, approximately 3500 lives are lost each year in rural communities due to this cause.

A special investigation of the fire hazards of rural communities has shown that the greatest loss as well as the greatest number of fires occurs to dwellings. Studies have also shown that one of the two principal causes of rural dwelling fires in Iowa is from sparks on roofs. Furthermore, it is thought that losses occurring from this cause are largely preventable.

The purpose of this study was to determine the nature of the sparks supposed to cause roof fires and to investigate the effectiveness of devices used for the control of chimney sparks.

The work reported in this manuscript is a part of the general project, "An Investigation of Wind and Fire Losses to Farm Buildings in Iowa", and is an outgrowth of the cumulative study of the rural losses.
REVIEW OF PREVIOUS WORK.

The fire problem has been receiving serious consideration from various sources for some time. The Actuarial Bureau of the National Board of Fire Underwriters has made the most authentic estimates of the fire waste of the nation as a whole.

Of particular interest in the field of rural fires is a report of the causes of farm fires made by a joint committee appointed and authorized by the Agricultural Committee of the National Fire Waste Council and the Farm Fire Protection Committee of the National Fire Protection Association. The relative importance of the causes were shown as follows (15):

- Defective chimneys and flues: 14\%\%
- Lightning: 10 \%
- Sparks on roofs: 8 \%
- Gasoline and petroleum products: 7.5 \%
- Matches and smoking: 6 \%
- Spontaneous combustion: 5 \%
- Stoves, furnaces and their pipes: 4 \%
- Hot ashes and coal, including open fires: 2 \%
- Miscellaneous and unknown: 43 \%

The percentage of fires caused by sparks on roofs is probably considerably greater than shown above. Many of the fires attributed to defective flues are really believed to be
caused by sparks. Statistics show that in Iowa sparks on roofs cause a relatively higher percentage of the rural fires than for the nation as a whole.

No investigational work has been reported which is related directly to the problem of chimney spark arresters. Considerable work has been done with regard to locomotive spark arresters (28) and a project has just been completed on tractor spark arresters but as yet has not been published. The problems in these two are essentially different from those confronted in the use of spark arresters for chimneys.

For some time, the seriousness of the losses caused by chimney sparks has been realized. For example, the annual reports of the Iowa state fire marshal have shown the magnitude of the losses from this cause.

The use of spark arresters is essentially a preventive measure. Such a step is of special importance in country homes, where a large number of fires, once started, result in a total loss to the building. George D. Mock, field engineer for the National Fire Protection Association, in his report entitled "A Rural Fire Survey of Story County, Iowa" (I7) states the following:

"Rural fire protection is undoubtedly of value but it is more important to prevent fires than to fight them. The fact that much time must necessarily be taken in responding to a fire on a farm, that delays are very likely, and that many conditions arise which will hamper the functioning of the fire department, make it imperative that the farmer practice fire prevention consistently and conscientiously."

The use of spark arresters for dwellings with combustible
roofs has not received widespread attention although some individuals have recognized their possibilities for some time. In looking through "The Official Gazette of the United States Patent Office" for the past twelve years, it was found that a number of patents have been taken out on chimney spark arresters, but at the present time very few concerns are manufacturing them on a commercial basis. Only rather recently have arresters been used to any great extent in rural communities.

The two types installed in Iowa during the past year or two have been the National spark arrester, manufactured by the National Supply and Service Corporation of Crawfordsville, Indiana, and the Pioneer spark arrester, manufactured by James Slocum of Detroit, Michigan. Both of these were used in tests conducted in connection with this project. There has been some trade literature issued by these manufacturers on their respective devices, but that seems to be the extent of the printed information available.

Work has been conducted by the Underwriters Laboratories concerning the ease of ignition of combustible roofing material when exposed to flames. Tests have also been run by the Bureau of Standards in determining the size of brand necessary to ignite wooden shingles under various conditions. This work was conducted primarily, however, to determine the relative hazard of adjoining fires to buildings with wooden shingle roofs.

No work has been reported with respect to the size or character of chimney sparks igniting combustible roofs.
ANALYSIS OF THE PROBLEM.

Farm Buildings in Iowa.

Iowa ranks first among the states in farm building investment which amounts to slightly over a billion dollars according to the 1930 census report. The value of farm dwellings is about 475 million dollars or nearly half the total. Nevertheless, the building investment which is influenced by the type of farming varies greatly with different sections of the state (Figure II).

A more significant map might have been presented by showing the investment in dollars per acre since the counties differ in size. However, the county has been chosen as the unit for comparison in other studies made in connection with this general project of which this manuscript is a part.

The practice of feeding hogs and beef cattle in the western part of Iowa has defined that area as the Western Meat Production Area. The meat production enterprise makes relatively heavy demands on shelter for both livestock and feed. Similar conditions are found in the Eastern Meat Production Area (Fig. 1).

The dairy enterprise established in the northeastern part of the state requires a heavy investment in buildings.

A lower building investment is found in the Cash Grain Area. This section is characterized by the large acreage of grain and relatively small acreage of pasture. Since the common
Fig. I. Types of Farming in Iowa.

Fig. II. Farm Building Investment in Iowa Counties (1930 Census).
practice is to market the grain immediately after harvest, fewer buildings are required. A less clearly defined area, but similar in other respects, is found in the extreme western section of the state.

The southern part of the state has an area defined as the Southern Pasture Area where the grazing of cattle is the main enterprise and requires a small building investment.

**Property Damaged.**

The value of buildings damaged, the number of fires, the amount of damage and the extent of damage are all shown in Table I over a four year period from 1930 to 1933. Most noticeable of the items is the dwelling loss which accounted for 53 per cent of the fires and over 48 per cent of the total loss or approximately two million dollars annually. Less than half the dwellings were totally demolished, but the resulting damage from that number constituted nearly 65 per cent of the total dwelling loss.

The dwelling fires in town and country were nearly equal in number, but the country loss accounted for nearly 80 per cent of the total. This might be largely explained by the fact that country dwellings are very often completely destroyed when a fire once breaks out. The towns included in this study, which are those with a population less than 2500, usually have the advantage of fire-fighting equipment.

Comparison of losses to the principal rural buildings can
be noted from Figure III, but, since most fires caused by sparks on roofs occur in dwellings, other items will not be taken up here.

The results shown in the tables and charts on property damaged and causes of fire were obtained as a result of the investigation being carried on under the general project, "An Investigation of Wind and Fire Losses to Farm Buildings in Iowa."

The Code of the State of Iowa requires that all fires which result in property damage of five dollars or more shall be reported to the state fire marshal by the fire chief, mayor or township clerk within one week of their occurrence. It was from the record of these losses during the years 1930 to 1933 that the data were secured for this analysis.

No doubt some losses which occurred in the state were not reported, but those which were are probably typical of the total number and therefore are of value in making the comparisons desired.

Causes of Rural Fires.

The discussion of the causes of fires must necessarily concern itself with 75 per cent of the losses, since 25 per cent of the fires were reported as "cause unknown." Furthermore, as shown in Table I, the fires of unknown origin caused 41 per cent of the total loss. The relative importance of the various causes is shown in Figure IV.
fig. III. Rural Losses by Buildings.
Seven known causes of fires are outstanding. Defective flues caused somewhat greater damage, although sparks on roofs caused nearly twice as many fires. The next five causes were approximately the same order of importance. Adjoining, defective heating systems, lightning striking unrodded buildings, defective wiring, and spontaneous combustion of hay and straw, were the five causes mentioned.

Since the greatest amount of loss resulted from dwelling fires, a special study was made to determine the cause of these losses.

Approximately 21 per cent of the dwelling losses were also reported as "cause unknown." Over twice as many dwelling fires of unknown origin were reported in the country as in towns, although the total number of losses for each was about the same. The fires have usually gained greater headway in the country before being discovered making it more difficult to determine the cause.

As shown by Figure V, the major known causes of dwelling fires were defective flues, sparks on roofs, defective heating systems and defective wiring. In the country, the distribution between defective flues and sparks on roofs was nearly the same, both in number and amount. In the towns, however, sparks on roofs caused over three times as many fires.

When all fires for the state are considered, including those occurring in towns and cities with a population of over 2500, about 30 per cent are reported caused by chimney sparks.
Fig. IV. Causes of Rural Fires.
Fig. V. Known Causes of Rural Dwelling Fires.
These figures readily show the significance of reducing this one cause of fires and the saving that could be effected thereby.

**Fires Caused by Chimney Sparks by Month.**

The rural losses plotted by month from this cause (Figure VI) show that most of the fires occurred during the winter and early spring months. The peak of the losses occurred in March. Table III shows that from May to October the losses were rather low.

The results can be explained by the fact that during the winter and early spring months, most of the heating is done allowing greater opportunity for the chimneys to become filled with soot and burn out when an exceptionally hot fire is built. During the winter, there are periods when the shingled roofs become dry and therefore are a greater hazard if live sparks leave the chimney. In the fall months, dry leaves deposited on the roof or in the eave spouts become an added hazard.

The peak losses during February and March can probably be credited to the fact that on mild days combustion is incomplete in many stoves allowing the chimneys to collect a large amount of soot. When a cold spell does come, the stoves are fired heavily, and thereby give off sufficient heat to burn out the flues allowing the hot soot particles to fall on the roof and ignite the shingles.
Table III. Fires Caused By Sparks On Roofs By Months.

<table>
<thead>
<tr>
<th>Month</th>
<th>1930</th>
<th>1931</th>
<th>1932</th>
<th>1933</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>55</td>
<td>64</td>
<td>34</td>
<td>50</td>
<td>51</td>
</tr>
<tr>
<td>Feb.</td>
<td>68</td>
<td>99</td>
<td>59</td>
<td>101</td>
<td>82</td>
</tr>
<tr>
<td>Mar.</td>
<td>94</td>
<td>122</td>
<td>65</td>
<td>89</td>
<td>97</td>
</tr>
<tr>
<td>April.</td>
<td>67</td>
<td>53</td>
<td>65</td>
<td>44</td>
<td>57</td>
</tr>
<tr>
<td>May.</td>
<td>18</td>
<td>24</td>
<td>21</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>June.</td>
<td>19</td>
<td>8</td>
<td>11</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>July.</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Aug.</td>
<td>5</td>
<td>10</td>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Sept.</td>
<td>16</td>
<td>8</td>
<td>16</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Oct.</td>
<td>23</td>
<td>6</td>
<td>16</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>Nov.</td>
<td>55</td>
<td>6</td>
<td>50</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>Dec.</td>
<td>63</td>
<td>15</td>
<td>49</td>
<td>38</td>
<td>41</td>
</tr>
<tr>
<td>Total</td>
<td>490</td>
<td>421</td>
<td>415</td>
<td>401</td>
<td>452</td>
</tr>
</tbody>
</table>
Fig. VI. Distribution of Fires Caused by Sparks on Roofs.
Desirability of a Spark Arrester.

As previously shown, the largest single cause of fires to Iowa farm dwellings is sparks on combustible roofs. Two points of attack give promise of reducing this loss:

1. Replacement of combustible roofs by fire resisting roofs.

2. Successfully breaking the sparks into fragments sufficiently small so as to prevent or greatly reduce the possibility of ignition. This can be accomplished by means of a spark arrester.

As new homes are being built, no doubt a large percentage will be covered with fire resisting material, but there are many houses in the state covered with combustible roofs which become year by year, more of a fire hazard. In almost every locality it is possible to find wooden shingle roofs badly weathered that should be replaced from the standpoint of fire safety but which still serve as a suitable shelter. For such homes, the spark arrester serves a real purpose in reducing the probability of a fire.

Requirements of a Spark Arrester.

A good spark arrester should fulfill the following requirements:

1. Present a maximum of protection against the release of large live sparks from the chimney.
2. Remain reasonably free from soot and other obstructions over an extended period of use.
3. Admit of easy cleaning should clogging occur.
4. Not interfere with the natural draft of the chimney.
5. Be made of a material which will be durable for a reasonable period of time.

Types of Spark Arresters in Use.

The two types of spark arresters believed to be in most common use throughout the Midwest were tested. One is the National and the other the Pioneer spark arrester.

1. The National spark arrester. This device, shown in Figure VII, consists of one-half inch mesh screen with either a galvanized or porcelain enamel finish. The particular arrester used in these tests had the enamel finish and was 12 x 18 x 15 inches in width, length and height, respectively. It is held to the chimney top by wires attached to the body of the arrester and thence to the anchor wire fastened around the chimney several bricks from the top. This arrester is designed with four narrow slot-openings on each side. Each of these slots provides a free opening \( \frac{1}{4} \) by 12 inches and has inturned lips with a spiked edge. The purpose of this arrangement is to guard against the escape of large sparks and chunks of burning soot until they are broken up into smaller pieces, at the same time allowing enough free opening to provide sufficient draft to the chimney.
if the screen becomes clogged.

2. The Pioneer spark arrester. This device is made as shown in Figure VIII. The particular size used in these tests is 11 by 15 inches at the bottom and 15 inches high. The side walls extend vertically 6 inches and from there are inclined in a roof-like form inward, making a cross section 5 by 11½ inches, and then straight upward for 4 inches. The top and ends are enclosed with the same material as the sides. On two sides are openings 1½ by 11½ inches directly above the inclined portion. These free openings are likewise supposed to provide sufficient chimney draft should the arrester become clogged. The inclined portions are evidently intended to interfare with the passage of soot particles which might otherwise be carried directly out through the openings.

The material used for this arrester consists of expanded metal lath fabricated so as to form diamond-shaped openings. According to the manufacturer, a cadmium finish is applied to the metal.

3. Other types. Several other types of arresters are known to be manufactured at the present time, but, as yet, their use has been very limited and therefore were not included in this study. Two new types have been placed on the market recently and apparently have some rather desirable qualities. One is an open-top arrester manufactured by the National Supply and Service Corporation, and the other is a double enclosed type known
as the Star spark arrester.

The Midwest Spark Arrester.

The spark arrester designed by Professor Henry Giese of Iowa State College will be designated as the Midwest spark arrester. This arrester differs somewhat from the conventional type, in that, instead of using a fine mesh with occasional free or open areas, it provides complete enclosure with a relatively coarse mesh screen. The primary function of this coarse mesh is to intercept large embers and either prevent their exit or break them into smaller, less dangerous ones. In using the coarse mesh screen it is believed that there will be less possibility of clogging than has been experienced under certain conditions in the past.

The arrester used for test purposes was 10 inches high, made of galvanized screen. The sides were of three-quarters inch mesh and the top, one-half inch mesh. Across the inside, three inches from the bottom, was a screen of one inch mesh as shown in Figure IX.

The principle involved is the use of a coarse intercepting screen along with finer protecting one, being so arranged that the sparks will ordinarily pass through the two in the order named. By this means, the embers will be broken up sufficiently small as not to ignite a wooden shingle roof.
Fig. IX. Midwest Spark Arrestor
EXPERIMENTAL.

Specific Objectives.

There are in the United States Patent Office files a number of records of attempts to provide all the desired qualities in one spark arrester. Usage demonstrated that when certain fuels are used, soot deposits collect rather rapidly and partial or total obstruction results. Later patents show a tendency towards the use of coarser mesh screens and clear openings of sufficient size to supposedly take care of draft requirements for the chimney even though the screen became clogged.

A study of past experiences with spark arresters in Iowa indicates:

1. That when combustion is incomplete either through the use of certain fuels, notably Iowa coal, or defective heating systems, sooting and clogging occur in a comparatively short time.

2. That the open passages in spark arresters have not proven adequate to supply the necessary draft for the chimney when the screen becomes clogged, even though the area of the opening aggregates the area of the flue. On occasions it has been necessary to remove spark arresters to make further use of the chimney possible.
In view of the fact that the potential demand for an efficient spark arrester is large, especially in rural communities, the specific objectives of this study are as follows:

1. To determine the source of sparks causing roof fires.
2. To determine the size of sparks or chunks of soot necessary for ignition.
3. To find the size of screen most desirable for a spark arrester.
4. To test several types of spark arresters in common use as to their efficiency in controlling sparks.
5. To build and test a new type spark arrester.

Source of Sparks:

The purpose of this study was to determine whether sparks from stoves passing directly up the chimney are responsible for part of the roof fires.

An attempt was made to duplicate conditions as found in the average dwelling. The set-up consisted of a heating stove known as "The New Vulcan". The stovepipe entered the chimney 8 1/2 feet above the floor. The chimney was clean and 2 by 2 1/2 brick in size, having inside dimensions 9 by 13 inches and the top extended three feet above the roof.

The following fuels were burned separately:

1. West Virginia coal.
2. Illinois coal.
3. Iowa coal.
5. Corn-cobs.

The work was conducted at night and a run of an hour made for each fuel with small quantities being added at ten minute intervals. To facilitate rapid burning, a two-blade 16 inch fan driven by a one-fourth H.P. motor was placed 15 inches in front of the lower draft opening of the stove. Observations were made from the roof to determine whether any live sparks left the chimney. The results were as follows:

No live sparks were observed when any of the grades of coal, wood or corn-cobs were used. There were occasional sparks from the paper fire but these floated off into the air and were dead before leaving the chimney more than a few feet.

In these tests, any visible sparks had to originate from the stove as the chimney and stovepipe were clean of all soot. It can be definitely concluded from this that roof fires are caused mostly not by embers originating in the fire box, but by incandescent, flaky particles spalling from the inside of the chimney wall. This material, usually high in creosote content, is ignited and released by the heat of a large fire.

Collecting Soot Particles.

In an attempt to determine more definitely the nature of the material causing roof fires, a number of chimneys were examined, some of which had been reported to have "burned out."
A number of soot samples were also taken and used in later work. On one occasion, the nature of the particles could be observed as they were being carried out by the draft in the flue. The fuel used in each case was primarily Iowa coal with some wood and corn-cobs.

As the soot was removed from the chimney, it broke up into rather flat, flaky, irregular shaped fragments of varying sizes up to about three inches in cross-section. A sample of these is shown in Figure XI. In all cases they were noted to be fragile when cold becoming more so when heated.

A large number of separate fragments were weighed and measured and the results shown in Table IV. It is realized that the measurements are only approximations since the particles were rather irregular, but an attempt was made to take the average dimensions in each case. They were all quite uniform, in thickness ranging from about one-fourth to three-eighths inches.

In some of the following tests it was desirable to know the weight of the soot samples after heating, but, since it was not possible to weigh these under such conditions, it was necessary to make a number of comparisons of the weight before and after heating. Such tests were made by taking samples of the weights shown in Table V and heating at the rate of six seconds for every tenth of a gram of weight. A gasoline burner was used for this purpose and the flame kept regulated to the same height for all the work. The average loss of weight was determined and found to be 50.4 per cent, and the relationship of original to
Table IV. Relationship of Size to Weight of Soot Particles.

<table>
<thead>
<tr>
<th>Number of Samples</th>
<th>Weight in Grams</th>
<th>Av. Size in Sq. Inches</th>
<th>Square Root of the Area</th>
</tr>
</thead>
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<tr>
<td>26</td>
<td>0.02</td>
<td>0.25</td>
<td>0.50</td>
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<td>0.03</td>
<td>0.43</td>
<td>0.66</td>
</tr>
<tr>
<td>23</td>
<td>0.04</td>
<td>0.55</td>
<td>0.75</td>
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<td>0.05</td>
<td>0.61</td>
<td>0.77</td>
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<td>0.06</td>
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<td>3.24</td>
<td>1.80</td>
</tr>
<tr>
<td>1</td>
<td>0.58</td>
<td>3.75</td>
<td>1.94</td>
</tr>
<tr>
<td>1</td>
<td>0.75</td>
<td>5.00</td>
<td>2.24</td>
</tr>
</tbody>
</table>
Table V. Loss in Weight of Soot by Heating.

<table>
<thead>
<tr>
<th>Number of Trials</th>
<th>Wt Before Heating</th>
<th>Avg. Wt After Heating</th>
<th>Percent Loss in Wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.05</td>
<td>0.02</td>
<td>60.0</td>
</tr>
<tr>
<td>20</td>
<td>0.10</td>
<td>0.06</td>
<td>40.0</td>
</tr>
<tr>
<td>20</td>
<td>0.20</td>
<td>0.09</td>
<td>45.0</td>
</tr>
<tr>
<td>20</td>
<td>0.40</td>
<td>0.22</td>
<td>57.2</td>
</tr>
<tr>
<td>20</td>
<td>0.60</td>
<td>0.30</td>
<td>50.0</td>
</tr>
<tr>
<td>20</td>
<td>0.80</td>
<td>0.38</td>
<td>52.5</td>
</tr>
<tr>
<td>20</td>
<td>1.00</td>
<td>0.53</td>
<td>47.0</td>
</tr>
<tr>
<td>20</td>
<td>1.50</td>
<td>0.73</td>
<td>51.3</td>
</tr>
<tr>
<td>20</td>
<td>2.00</td>
<td>0.98</td>
<td>51.0</td>
</tr>
</tbody>
</table>

Fig. I. Calibration for Finding Weight of Soot after Heating.
final weights was plotted in Figure X. Representative samples were taken of the soot from different chimneys, and therefore in any of the tests where the weight of the heated sample is desired, it can be found, knowing the weight of the sample before heating.

**Clogging of Arresters.**

Both the Pioneer and the National spark arresters have been reported unsatisfactory under certain conditions due to the fact that they clogged rather readily, thereby restricting the natural draft of the chimney. Such a report has come from Henry County, Iowa, where the National spark arrester is used, and from Webster County, Iowa, with regard to the Pioneer spark arrester.

The Pioneer arrester was placed on the test chimney, using Iowa coal as fuel, in an attempt to determine the rapidity with which clogging takes place. A considerable coating of soot was noticeable by the third day which increased up to the eighth day (total of 63 hours burning) when a very strong wind blew out most of the deposit. It was therefore impossible to photograph the actual condition at that time, but a part of the openings were reduced by as much as 40 per cent. This was especially true on the side opposite the direction of the prevailing wind.

Since the Midwest arrester had not been tested by usage in this respect as had the other two, it was thought desirable to keep the arrester on the test chimney for the remainder of
the time available. This period extended over 203 hours of actual burning. The weather ranged from warm calm days to some that were rather cold and windy. Figure XII shows the arrester after being removed. This is probably far more sooting than would result under ordinary conditions because a smouldering fire was maintained most of the time causing incomplete combustion and a large amount of smoke. It was thought desirable, however, to test the arrester under the worst conditions as these might be met occasionally in practice. The greatest amount of clogging, occurring near the bottom of the arrester, reduced the actual openings in the three-fourths inch mesh from five-eighths to seven-sixteenths inches or about 50 per cent. The reduction in the inch mesh was practically negligible. Observations were made three times daily and the following might be noted:

The soot deposit does not increase at a uniform rate. The fuel, method of firing, and weather all have their influence, the latter being the greatest factor. The draft in the stove is affected by the outside temperature and this in turn influences the fire. On warm calm days the draft is reduced and more unburned fuel particles leave the flue as smoke causing rapid clogging. Rain or wind helps to remove part of the deposit already formed. The collection of soot is rather light and fragile and therefore the wind serves a very helpful purpose in keeping this removed.

Further tests were made by placing screens in the path of
Fig. XI. Soot Particles from Chimney.
the smoke and noting the rate of clogging. Each screen was placed inside the test chimney 18 inches from the top. It is realized that this does not approach ordinary conditions, but it gives a better method of comparing one size mesh with another since the unequal effect of wind from day to day is eliminated. Furthermore, a similar situation might be approached in a spark arrester if it is in use during an extended period of very little wind. The results obtained were as follows:

1. One-third inch mesh. The amount of clogging as shown in Figure XIII resulted after 20 hours. It can be seen that complete obstruction occurred in some areas. The conditions were favorable for rapid sooting as a slow-burning fire was maintained.

2. Three-fourths inch mesh. Figure XIV shows this screen after 90 hours placed under the same conditions as that above. There were two light rains during this time but neither of these seemed to remove any large amount of the deposit. The openings in the screen have been reduced between 50 and 60 per cent.

After being taken from the chimney this screen was placed first in a 6 and then in a 12 mile per hour wind for three minute periods. The 6 mile wind had little effect, but the 12 mile wind carried out the deposit almost immediately leaving the screen as shown in Figure XVI.

3. One inch mesh. This test was likewise run for 90 hours and at the end of that period a considerable soot deposit was noticed but it dropped out in the process of removing the screen
Fig. XIV. Screen with three-fourths Inch Mesh.

Fig. XIII. Screen with three mesh to the Inch.
due to slight jarring.

From this work, it seems that a certain amount of soot deposit can be expected for both large and small mesh screen, but it is more easily removed by the wind in the larger size meshes and therefore becomes a less serious problem.

Desirable Material for a Spark Arrester.

The time allotted to this project did not permit making any conclusive tests as to the desirability of the present coatings used for the metal, and neither was it possible to get this information from arresters in use as they have been installed too recently for that purpose. The material must be of such nature as to withstand relatively high temperatures and corrosion both from moisture in the atmosphere and the chimney gases. The analysis of a sample of coal from Boone County, Iowa, (Table VI), shows the high sulphur content. This condition is typical of Iowa coal and is an important factor in corrosion.
Table VI. Analysis of Coal from Ogden, Iowa.

<table>
<thead>
<tr>
<th></th>
<th>As Received Per Cent</th>
<th>Dry Basis Per Cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>13.61</td>
<td></td>
</tr>
<tr>
<td>Volatile Combustible Matter</td>
<td>52.97</td>
<td>61.32</td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>26.42</td>
<td>30.58</td>
</tr>
<tr>
<td>Ash</td>
<td>7.00</td>
<td>8.10</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Sulphur</td>
<td>5.15</td>
<td>5.96</td>
</tr>
<tr>
<td>B.T.U. per Lb.</td>
<td>11300</td>
<td>13080</td>
</tr>
</tbody>
</table>

The National spark arrester is made with either a galvanized or porcelain enamel coating. It is claimed that the latter will far outlast the former. The life of a galvanized material will depend upon the fuel used and the frequency with which the flue burns out. High temperatures will destroy the galvanized coating rather quickly. A noticeable objection to the porcelain enamel coating is that, in handling or shipping, a certain amount of the enamel is easily chipped off leaving the exposed iron readily susceptible to corrosion.

During the course of this work, a piece of galvanized hardware cloth was hung in the test chimney 12 inches from the top and remained there during 203 hours of burning. At the end of that time, the galvanized coating did not appear to be seriously affected. However, at no time was the temperature in that part of the flue known to exceed 600 degrees Fahrenheit. This
might tend to indicate that, at reasonably low temperatures, a galvanized screen could be expected to give satisfactory service for a considerable length of time.

It was not possible to measure the temperature of a flue while it was burning out. A large number of measurements at the top of the test chimney showed an average temperature of 385 degrees Fahrenheit when there was a hot fire in the stove. It is realized that each heating system would show different results, depending upon the draft, type of stove, location of stovepipe entrance to the flue, etc., but this set-up is rather typical of the average dwelling.

The cadmium finish as used on the Pioneer spark arrester seems to be the most desirable material now in use. Here again, time did not permit making any conclusive tests, but the arrester was in use on the test chimney 8 days during which the arrester became well coated with soot. At the end of the period, it was easy to clean off this deposit leaving the metal coating unaffected.

**Size Brand to Ignite Wooden Shingles.**

Since the chief function of a spark arrester is to break up the soot particles sufficiently small so as not to cause a fire when falling on a combustible roof, one of the important parts of this work was to determine the maximum allowable size. Upon this depends the size of screen safe to be used and it is desirable to have as large a mesh as possible to reduce the
possibility of clogging. Actual soot particles were heated and used for this purpose.

For these tests, three grades of red cedar shingles were used and sections of roof 24 by 28 inches were constructed from each with the shingles laid 4½ inches to the weather. The roof deck was made from 1 by 4 inch sheathing spaced 4 inches apart. The first grade consisted of old shingles, badly weathered and rather loose and curled in many cases. This was intended to approach the worst condition in which dwelling roofs would probably be found. In addition, all shingles were well dried. The second grade represented old shingles in fair to good condition as would be found on an old roof considered in good repair. The third included sections made from the best grade new cedar shingles.

Each roof section was set up at a quarter pitch. Electric fans furnished a three mile per hour wind. Samples of soot were weighed and heated in the manner explained previously. These were then dropped on the roof falling as near as possible between the shingles where they remained for three minutes. If at the end of this time the wood had ignited, the sample was considered as starting a fire. This procedure was repeated for various sizes of soot samples, weighed before heating, until the minimum weight sample was found below which ignition did not occur, up to the size causing 100 per cent ignition as shown in Tables VII and VIII. Separate chunks of soot were used as much as possible, but the larger samples were made up from a number
of fragments. These were deposited on the roof to a depth of a 
half inch so as to approach one large piece as far as possible. 
The results found are as follows (Figure XV.):

1. Badly weathered shingles. The smallest size brand caus-
ing ignition weighed 0.07 gram before heating. According to the 
work reported earlier in this manuscript, this would be a frag-
ment about one-fourth inch thick and having an area approximat-
ely 0.86 square inches. This size could not pass through a three-
fourths screen. A smaller brand apparently will not ignite 
shingles even under the ideal conditions as occurred in this set-
up. The requirements placed upon a spark arrester should be to 
further break up or retain any live sparks more than 0.03 or 0.04 
grams in weight. This allows a 50 per cent reduction in weight 
to the soot by heating. Any smaller particles might be allowed 
to leave the chimney and thereby reduce the accumulation in the 
flue.

2. Old shingles in good condition. The results show that 
old shingles in good condition are not ignited by heated soot 
particles less than about 0.10 to 0.15 grams in weight. This 
would be a fragment approximately 1 inches square.

3. New shingles. From the results shown in Table VIII, it 
is very unlikely that sparks are a very prevalent cause of fires 
to a new roof or one in very good condition. It was impossible 
to get single soot particles of sufficient size for these tests 
as it would require a chunk about 3 inches square to cause igni-
tion under such conditions.
<table>
<thead>
<tr>
<th>No. of Trials</th>
<th>Wt. in Grams Before Heating</th>
<th>Wt. in Grams After Heating</th>
<th>Number Ignited</th>
<th>Per cent Ignition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor Condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.06</td>
<td>0.03</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0.07</td>
<td>0.03</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>20</td>
<td>0.08</td>
<td>0.04</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>0.09</td>
<td>0.04</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>0.10</td>
<td>0.05</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>0.15</td>
<td>0.07</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>0.20</td>
<td>0.10</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>20</td>
<td>0.30</td>
<td>0.15</td>
<td>9</td>
<td>45</td>
</tr>
<tr>
<td>20</td>
<td>0.50</td>
<td>0.25</td>
<td>16</td>
<td>80</td>
</tr>
<tr>
<td>20</td>
<td>0.30</td>
<td>0.40</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Good Condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.20</td>
<td>0.10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0.30</td>
<td>0.15</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>0.40</td>
<td>0.20</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>0.50</td>
<td>0.25</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>20</td>
<td>0.60</td>
<td>0.30</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>20</td>
<td>0.70</td>
<td>0.35</td>
<td>16</td>
<td>80</td>
</tr>
<tr>
<td>20</td>
<td>0.80</td>
<td>0.40</td>
<td>17</td>
<td>85</td>
</tr>
<tr>
<td>20</td>
<td>1.00</td>
<td>0.50</td>
<td>20</td>
<td>100</td>
</tr>
</tbody>
</table>
Table VIII. Size of Brand to Ignite New Shingles.

<table>
<thead>
<tr>
<th>No. of Trials</th>
<th>Wt. in Grams Before Heating</th>
<th>Wt. in Grams After Heating</th>
<th>Number Ignited</th>
<th>Per cent Ignition</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.40</td>
<td>0.20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0.60</td>
<td>0.30</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>0.60</td>
<td>0.40</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>20</td>
<td>1.00</td>
<td>0.50</td>
<td>11</td>
<td>55</td>
</tr>
<tr>
<td>20</td>
<td>1.50</td>
<td>0.74</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>2.00</td>
<td>0.99</td>
<td>20</td>
<td>100</td>
</tr>
</tbody>
</table>
Fig. XV. Size Brand to Ignite Wooden Shingles.
In actual practice the probability of ignition would be considerably less than shown by these results. In the first place, each sample was dropped in the space between the shingles where the possibility of ignition was the greatest, especially on shingles badly weathered. Furthermore, all samples were heated and placed directly on the roof thereby bringing a hotter brand in contact with the wood than would usually be the case. The top of the ordinary chimney is several feet above the roof. If a hot soot particle drops through this distance, considerable cooling will take place, especially with the smaller sizes. Realizing these deviations from actual conditions, it was still thought desirable to follow the procedure outlined. More of the variables could be eliminated in this way and a fairer comparison made between the different samples of shingles. Besides, in practice, a certain combination of conditions occasionally creates one which is ideal, and therefore a spark arrester, to be the most effective, should retain even those sparks which can ignite only under the ideal conditions.

Efficiency of Arresters in Breaking up Sparks.

These tests were conducted to determine first, the percentage of material above a certain size which could escape through the arrester and, second, the nature of the live soot particles allowed to pass.

In making these determinations, a model of a chimney was
built of sheet metal 30 inches high and with cross sectional dimensions 9 by 13 inches, the same as the inside measurements of the chimney. Upward draft was provided by means of an electric fan sufficient to raise the soot particles 3 feet above the top of the chimney.

Tests were made on each arrester with respect to the size material allowed to pass. For this purpose unheated soot particles were used which would not pass through half inch mesh hardware cloth. The particles ranged in size mostly from a half to one and one-fourth inches. One-half gram samples were used for each run and these were placed inside the chimney on a screen 9 inches below the top. The fan providing the cross draft was started first and then the one beneath the chimney, blowing the soot particles against the arrester. Each run lasted 60 seconds. The material passing through the arrester was screened the second time and the weight determined which would not pass the half inch mesh. Results are shown in table IX. The following might be noted with respect to each arrester:

I. National spark arrester. A sample of the material that passed through is shown in Figure XVII. This shows that most of it was broken up quite fine, but 9.1 per cent was over a half inch with a few pieces over an inch. All the larger material passed through the free openings on the side opposite the direction of the wind. The air stream caught these particles and in most instances carried them nearly horizontally through the openings.
### Table IX. Size Material Passing Through Arresters.

<table>
<thead>
<tr>
<th>Name</th>
<th>Wt. of Each</th>
<th>Total Wt.</th>
<th>Wt. Over 1/2 Inch Pass—Over 1/2 Inch Pass Through in Grams</th>
<th>Per cent Over 1/2 Inch Pass—Over 1/2 Inch Pass Through in Grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>National</td>
<td>0.50</td>
<td>10</td>
<td>0.91</td>
<td>9.1</td>
</tr>
<tr>
<td>Midwest</td>
<td>0.50</td>
<td>10</td>
<td>0.42</td>
<td>4.2</td>
</tr>
<tr>
<td>Pioneer</td>
<td>0.50</td>
<td>10</td>
<td>1.20</td>
<td>12.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Wt. of Each</th>
<th>Total Wt.</th>
<th>Wt. Over 1/2 Inch Pass—Over 1/2 Inch Pass Through in Grams</th>
<th>Per cent Over 1/2 Inch Pass—Over 1/2 Inch Pass Through in Grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>National</td>
<td>0.50</td>
<td>4.96</td>
<td>0.29</td>
<td>5.8</td>
</tr>
<tr>
<td>Midwest</td>
<td>0.50</td>
<td>4.96</td>
<td>0.26</td>
<td>5.2</td>
</tr>
<tr>
<td>Pioneer</td>
<td>0.50</td>
<td>4.96</td>
<td>0.53</td>
<td>10.7</td>
</tr>
</tbody>
</table>
2. Pioneer spark arrester. Conditions here were similar to those in the previous test except that a somewhat greater amount of the larger material passed through the free openings (Figure XVIII.) The sloping sides below the openings did tend to keep a large amount of the material from getting out until broken up, but 12 per cent of the material passing through was over a half inch and a considerable amount of this was over one inch and therefore not broken up at all.

It might be noted that this set-up, having the wind at right angles to the openings, gave the greatest opportunity for large material to escape in both this and the preceding test. Nevertheless, such condition would probably occur quite frequently in practice and therefore this test is not considered unfair. There is reason to believe that even larger particles than those used could pass through the free openings.

3. Midwest spark arrester. In general, this arrester did not break the particles up as fine as the other two. A large number were from one-fourth to nearly one-half inches, Figure XIX, but only 4.2 per cent by weight of the material was over one-half inch and not larger than five-eighths. Anything of this size would be too small to start a fire.

Further tests were made to determine the nature of the heated soot particles after passing through the arresters. The procedure was the same as that above except that each half gram sample was heated by the gasoline burner in the manner previously described. The particles remained approximately the same size.
Fig. XVIII. Soot Particles Passed Through Pioneer Arrester.

Fig. XIX. Soot Particles Passed Through Midwest Arrester.
after heating despite the loss in weight. They were easily broken when striking any part of the arrester but some large fragments passed through the free openings of the Pioneer and National. In the former, 10.7 per cent of the material passed through was over a half inch. The National and the Midwest arresters showed up about equally in this respect with 5.3 and 5.2 per cent respectively. The primary difference was, however, that none of the fragments passing through the Midwest arrester were over five-eighths inches, the maximum that can get through the mesh, whereas with the other, some particles measured over an inch. The relationship of the sizes for the Pioneer and Midwest arresters can be seen in Figures XX and XXI.
Fig. XX. Heated Soot Particles Passed Through Pioneer Arrester.

Fig. XXI. Heated Soot Particles Passed Through Midwest Arrester.
SUMMARY AND CONCLUSIONS.

A summary of the work reported includes the following points:

1. A study of the principal causes of rural fires in Iowa.
2. Analysis of requirements and present designs of spark arresters from which a new design resulted.
3. Determination of the source and nature of sparks causing fires and the size of brand necessary to ignite wooden shingles.
4. Tests on several types of spark arresters to determine their efficiency in preventing dangerous sparks from leaving a chimney.
5. A discussion of the results of tests from which conclusions were drawn.

Conclusions.

1. The greatest single cause of rural fires in Iowa is from sparks on combustible roofs.
2. Rural fires caused by sparks on roofs occur mainly from November until April.
3. The most promising point of attack in reducing this item is to break up chimney sparks into fragments sufficiently small to prevent the chance of ignition. This can be ac-
accomplished by means of a spark arrester.

4. Sparks causing roof fires originate mainly from soot accumulations inside the flue.

5. Under certain conditions, heated fragments of soot over 0.75 to 1.00 square inches in cross section and weighing 0.03 to 0.04 grams or more will ignite wooden shingles.

6. Both the Pioneer and the National spark arresters allowed some particles to pass of sufficient size to cause a roof fire.

7. The soot particles leaving a chimney are easily broken up by striking a screen, but pass through intact readily any opening larger than their greatest dimension.

8. With the use of certain fuels, some degree of clogging can be expected with any of the spark arresters tested, but the rate and amount decreases with an increased size of mesh.

9. A satisfactory type of spark arrester seems to be one which is fully enclosed having a wire mesh small enough to successfully retain or further break up any sparks larger than about 0.75 square inches in cross-section, but as large as possible to reduce to a minimum the possibility of clogging with soot. These features are believed to be included in the Midwestern spark arrester.
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ACKNOWLEDGMENTS.

The author herewith wishes to express his appreciation to those who, through their kind assistance and cooperation, have contributed so largely to this project.

Invaluable support and cooperation were received from Professors J.B. Davidson and Henry Giese and other members of the Agricultural Engineering staff at Iowa State College. Much helpful assistance was also received from individuals not connected with this department.

Mention is made of the Iowa Mutual Tornado Insurance Association and the Iowa Farmers' Mutual Reinsurance Association, donors of this fellowship, and especially H.F. Gross, secretary of the Iowa Mutual Tornado Association, and John Evans, secretary of the Iowa Farmers' Mutual Reinsurance Association.

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