## STUDY ON FORMING MECHANISM OF THE FIRESTORM IN THE FOREST AND ITS CONTROLLING COUNTERMEASURE

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### ABSTRACT

**This paper advancs the general structure of the forming mechanism of firestrom in the forest through analysis on forming and developing process of the forest fire from the angle of combustion and gas dynamics under the boundary conditions given. It maintains that a great forest fire would produce a large quantity of combustible gases on account of combustion in the condition of insufficient oxygen. These gases would burn again and so forme the firestorm. The general features of the firestorm and its disastrous consequences are showed clearly. The theory is verified with the exterior characteristics displayed by the firestorm on a macroscopic scale with concrete cases. The paper, finally, proposes the controlling countermeasures.**

**KEY WORDS:** **firestorm in the forest, Combustion on account of insufficient oxygen.**

### INTRODUCTION

**The firestorm is a kind of drifting wild fire. Up till now, there is no effective way of putting out such a fire, and the fire is always disastrous. What is more, our understanding on the fire is limited to the degree of superficial, external phenomenal descriptions. It is absolutely unnecessary to study its forming mechanism and its developing patterns, so as to control it.**

### EXPERIMENTS

**During the period of the big fire in the Great Xing'an Mountains in Heilongjiang province, which fired on May 6th, 1987, (known as the May 6th Fire), we surveyed and observed from the air the area over 1.14 millon bectares that was on fire, and photographed many scenes from the Double Otter plane with the infrared photoraphing function.**

**We also observed and recorded the meteorological phenomena of the fired area. The temperature, the barometric presure, the air humidity, the wind velocity, and the wind direction at 2:00p.m. ever-**

yday are noted down.
After the fire, we sampled four pleces of land close to the fire area and measured weight and depth of all levels of vegaetation. We also widely interviewed the firemen, many of whom witnessed the phenomena of drifting fire, flying fire, explosion in the air and dense fogetc.

## THE COMBUSTION OF COMBUSTABLE MATERIALS AND THERMAL EFFECT

The fuels are organic substances Mixed with the oxygen in the air under high temperature, they could lead to physical–chemical reactions demonstrated as following (ig.1)

$$2C + O_2 = 2CO \qquad (1)$$

$$C + O_2 = CO_2 \qquad (2)$$

When the combustion temperature reaches 700℃ or above, the combustion will be intensified and it will produce much more CO, which may result in the hydrogen in fuels participating in these reactions:

$$2CO + O_2 = 2CO_2 \qquad (3)$$

$$2H_2 + O_2 = 2H_2O \qquad (4)$$

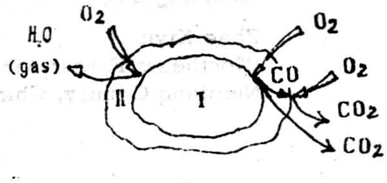


Fig.1 Thecombustionofcombustibles
I .combustibles; II .combustinglayer

All these four kinds of reaction are exothermic reactions. Under the open boundary condition of the forest fire, te barometric presure equals the ambient pressure, the air density is constant, so the thermal effect of the combustion is a physical–mathematical question of the Fourier–Kosih of's euqation[2]:

$$\frac{\partial T}{\partial t} = \frac{\lambda}{c.p.r}\left(\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \partial^2 t / \partial z^2\right) - \left(Wx\frac{\partial t}{\partial x} + Wy\frac{\partial t}{\partial y} + Wz\frac{\partial t}{\partial z}\right) \qquad (5)$$

where, T is temperature, (℃): t is time, $\lambda$; is thermal conductivity, (K Ka / s M℃); Cp is thermal volume, (K Ka / m℃ ); r is specific gravity, (Kg / $m^2$);X,Y,Z are components of tricoordiante, (M); Wx, Wy, Wz are projections of velocity in the tricoordinate (M / S). Posture (5) indicates that the partial fluctuation of temperature ($\frac{\partial T}{\partial t}$)caused by the combustion will produce local thermal convection and temperature rise.

## THE PRELIMINARY BOUNDARY CONDITIONS OF THE FIRESTORM IN THE FOREST

After careful observation and analysis on the May 6th Fire, we conclude that preliminary boundary conditions of storm fire are (a) dense vegetation; (b) intense combustion on big area; (c) appearence of regions with many a burning spot known as the "leopard–spot fire" caused by wind gusts.
Surveying the four sample lands in the Great Xing′ an Mountains, we find that the average depth of the effective fuels on the ground is 0.103–0.910 M, and its volume of the effective combustible matterials is 1.18–2.90Kg / $m^2$(table 1).

Table 1 Depth and Load of the Fueles of the Great Xing'an Mountains

| Combustibles | Depth of upper level(M) | Depth of lower level(M) | Depth of the dead branches and leaves (M) | depth (M) | Load ($Kg/m^2$) leaves(M) |
|---|---|---|---|---|---|
| Larch | 0.025 | 0.028 | 0.050 | 0.103 | 1.18m) |
| Secondary Forest | 0.080 | 0.042 | 0.090 | 0.212 | 2.69 |
| Grass land | 0.230 | | 0.230 | 0.460 | 1.60n) |
| Grass land | 0.500 | | 0.410 | 0.910 | 2.90 |

m). Cleared up in 1987. n) Undergone a fire in 1987.

that the rate of producing combustible gases of arbor is about 20%–50%; herb,10%–30%; and bush, 10%–20%,all of which are with in the combustible density range.

As mentioned above the intensifled combustion on a big scale in the oxygen thin state will produce many combustible gases, which mixs with the air, maintains within the combustible density range, and will burn again intensely in a reinforeed manner when cirecumstancse suit. This is basic forming mechanism of the fire storm in the forset.

## THE ESSENTIAL FORMING CONDITIONS OF THE FIRESTORM IN THE FOREST

(1)Meterological conditions:

A. Strong polymerization between eyclons:The combustible gases are stuck in the cyclon and cannot drift away out of the fire area because of the low pressure on the area. During the May 6the Fire, the Amur Meteorological Observatory noted down a drop in pressure of 100h.Pa per hour. B. High temperature: High temperature will reduce the air humidity, which can intensify the commbustion and help produce large quantity of combustible gases. On the May 6the Fire, the air humidity of the fire area at Amur was only 5%.

(2). Geographical and topgraphical conditions.

The grographical position of the fire area will have a meteorological effect on it. For instance, Inner Mongolia and the Northeast region of China is often under the effect of frontal whirlpools.

In the intensified combustin of this large amount of fuels, the flames could reach as high as 2.0–3.5 metres, which produces thermal currents above 20 metres high, mixed with dusts and tiny igniging metters. these tiny igniting matters are likely to drift off quite some distance away carried by gusts of wind or thermal currents, and then they drop on the ground when the wind and the thermal currents slow down or die away and these igniting matters could no longer sustain their own weight in the air. They scatter around burning fire line and set dotty new fire spots which are called "leopard–spot flying fire"(Fig.2) The picture of Fig.3 was taken during the May 6th Fire in northeast of Mohe county, which proves the existence of the " leopard–spot fire" in the developing process of the firestorm.


Fig.2 The formation of the flying fire focus

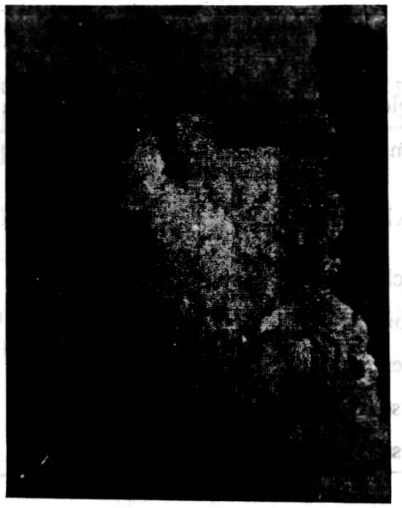

Fig.3 A whirlpool in the northeast of the Mohe county in the May 6th Fire

## THE FORMATION MECHANISM OF THE FIRESTORM

From our observation of the May 6th Fire, we know the width of "leopard–spot fire" area is about 100 metres. As dense smoke shrouds the whole buring area, large amoutnt of oxygen is in need of combustion of " Leopare–spot fire" leaving the buring area in an oxygen–thin state, where the reacton is that of poture (1), That is to say, a large amount of combustible gases like CO are produced. The fire area is 1000 metres long and 100metres wide, with $1.5Kg/m^2(C=49.7\%)$ effective fuels.We assume that the oxygen in the area is 20% less than normal. According to posture(1), we know that 1 gram C molecul produces i gram CO molecule ($=0.0224m^3$),Thus the volume (v) of the CO gas produced is

$$V=\frac{1.5(1000\times 100)20\%}{12\times 11000}\times 0.0224\times 49.7\%=2.76\times 10M^3$$

Alhough the 20% lack of oxygen is hypothetical and may not be precise, it doesn't affect the conclusion we have come to. That is, a large amount of combustible gases will be produced under the oxygen–thin state. It is the most important to our study of the firestorm.

It is well known that the combustible gases could not catch fire unless their densiey is large enough (tableⅢ)[3].

Table Ⅱ

| Types of the | Combustible density (%) | |
|---|---|---|
| | combustible gas | Lower Limit |
| Upper Limit | Carbon monoxide | 12.50 |
| 74.20 | Methane | 5.00 |
| 15.00 | Ethane | 3.22 |
| 12.45 | Hydrozen | 4.00 |

The ombustible density range of CO is between 12.5% and 74.2%. Therefore, the volume of the mixed combustible air is 8.00–1.35(1 / 0.125–1 / 0.742) times the size of the combustible gas. From the hypothesis above, we know there could be 0.373–2.208$M^3$mixed combustible air derived from every square metre of the burning field.

Experiment of simulated combustion in aritight dry distillation without oxygen of 10 species of forest vegetations shows (table Ⅲ) topographical condition, on the other hand, will affect the air current of the fire area. For example, the circular or semi–cicular mountain organge could produce whirplool, while a long, narrow valley will cause the air to move along side.

Table Ⅲ The content of combustible gases in different combustible

| Mames of festing fueles | Positions of thesting fueles | The portions of gases(%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CO | O[n] | O | CO | H | S[b] | N | T[c] |
| Larch | Sopwood | 37.30 | 2.40 | 2.60 | 30.10 | 0.57 | 18.672 | 8.41 | 51.69 |
| Larch | Bank | 44.60 | 1.70 | 1.50 | 19.73 | 0.42 | 6.97 | 25.06 | 28.64 |
| Larch | Dry brnch | 37.90 | 2.15 | 3.00 | 19.61 | 0.30 | 12.20 | 24.84 | 34.62 |
| Scotch pine | Trunk | 31.35 | 1.00 | 4.15 | 14.20 | 0.16 | 5.84 | 43.30 | 21.20 |
| White birch | Trunk | 39.80 | 0.80 | 5.00 | 10.82 | 0.20 | 7.52 | 26.84 | 28.36 |
| Aspen | Trunk | 46.30 | 2.10 | 2.70 | 27.40 | 0.66 | 10.29 | 10.55 | 40.45 |
| Japanses | Dry branch | 39.20 | 1.30 | 3.70 | 14.70 | 0.20 | 2.41 | 38.49 | 18.61 |
| Creeping | juniper | 25.00 | 1.00 | 3.60 | 6.00 | 0.13 | 7.54 | 55.83 | 14.67 |
| Hazel | Stem and leaf | 47.20 | 2.00 | 2.40 | 13.30 | 0.12 | 6.26 | 28.72 | 21.68 |

## THE CHARACTORISTICS OF THE FIRESTORM AND ITS HARMFULNESS

(1).Drifting fire.

This is caused by the combustion of the driftin combustible gas masses. When the drifting fire wave, they usually waft upward, and are called updriftion fire. If they drift along the ground with the wind, they are called floor–drifting fire. In several interviews with the firemen who had participated in putting out the May 6th Fire, many of them claimed to have seen . The flames were 200 metres high. Some others described that in an instante a large part of the forset on the opposite mountain was on fire. The fire just flew thereover the top of the trees with great noises .This is an obviouse case of the drifting fire. It may cause severely destruction to forests and towns in the forest.

(2).A whirlpool and whirlpool masses

Affected by the topographical or meteorological conditions,single whirlpool.(Fig 3) or multi–(whirlpools) may be formed. Some (whirlpool) can reveolve and rotate. This is called "whirlwind fire". The whirlpooles can carry with the igniting matters and keep them in high temperature. These igniting matters will drop on the ground along the trail of the whirlpool and make new fires at good distance away from the main fire area. In the May 6th Fire, The recorded disstance that"Flying fire" went is 2 kilometres.

(3).Sound and flash.

The combustion and explosion of the combustible gases can produce great noise together with bright flashes. During the May 6th Fire, several such explosions occurred. Some of the firemen said."just like the explosion of petrol tanks. But we never found any traces of explode petrol tank afterward".

(4).Dense layer of fog

Heavy combustion can form thick layers of smoke and fog, which is characterized by large scale and heavy density. It can greatly reduce the content of oxygen in the air.

In 1915, the Siberia had a big fire. Dense fog shrouded an area of almost 1.60 million square kilometres[5]. In the May 6th Fire, the oxygen content in the air was so low that it was impossible to have three cars started and they were later devoured by the fire.

## COUNTERMEASURES

Our study has shown that fire storm contains enormous energy, and it is impossible to put such fire out in the usual, direct–confronting way, It could only be done with indirect way to control it. At present, the measure that could be adopted are:

(1).Forest fire prevention.

A. Establish the partition system. Set up herbiciding zones and zones of turned up soil and with herbicids without any fuels. Also plant Fire–breaking forests, So to form a close partition network together with rivers,lakes,highways and railways as muuch as possible. B.Planned burining. The forest areas should undergo controlled burning regularly, to avvoid breaking out intensified fire.

(2). Indirect controlling measures.

A practical method would be to set fires to confront direction of moving the big fire. That is to burn down the vegetation in a small scale in the would–be path of the fire, to cut the way of the fire out. This could be performed on the ground by man or arial ignition system on a plane.

## CONCLUSIONS AND QUESTIONS

The experiment of the combustion of forestry vegetations in oxygen–thin,airtight distillation, which proves that under the oxygen–thin condition, large amounnt of combustible gases are produced within the combustible density range in the combustion of the fuels could largely illustrate the situation of the forest firetorm. Therefore, theory is convincing and tenable. We believe our theory that has shed light on a new research way of the firestorm in forest which has long been in a standting state. Still, the conclusion we draw from our research is initial. It lacks the on–the–spot tests and statistics of forest fires. So it needs further researhing to substantiate and modify the theory.

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