Future Fire Science

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ABSTRACT

A prospect has been performed on fire science in the future. For establishing a reliable fire safety management system and operating it effectively, knowledge in fire science is indispensable. The achievement of basic fire research is necessarily for the fire safety management. For establishment such situation, researchers for fire science have to make efforts to provide fundamental knowledge needed for mitigate fire losses to be occurred in the future. The most important knowledge effective for future fire safety must be of basic phenomena such as combustion, mass and heat transfer, and gas flows. Following a brief introduction into a fire safety management system, examples of anticipated basic knowledge for the future fire science are presented. It is inferred that most issues in the future fire safety can be resolved on the basis of knowledge on basic phenomena in fires.

KEYWORDS: prospect, fire science, combustion, transfer phenomena, aerodynamics

INTRODUCTION

For mitigating fire losses, we need an appropriate system for fire safety. Based on such a system, we could effectively manage actions for fire safety and provide facilities and instruments needed for improving safety level against fires. In planning individual actions for fire safety and evaluating the effectiveness of the facilities and instruments, knowledge on phenomena in fires is indispensable [1,2].

Almost all of basic concepts for minimizing fire losses are based more or less on knowledge of basic phenomena. However, it seems rare so far to utilize appropriately knowledge accumulated throughout basic studies on phenomena in fires for developing or improving the technologies. It has been pointed out that if a person dealing with fire modeling, building design, evacuation planning, detector development, fire suppression system design, or fire fighting tactics would have sufficient knowledge of phenomena at fires, he could obtain more reasonable results. On the other hand, in general, the data and models concerning basic phenomena can hardly be involved in the procedure to develop technologies for fire protection. Thus, efforts are needed to transfer basic knowledge on phenomena in fires to practical activities for fire protection.

The most effective means for the transfer of basic knowledge must be dissemination of a system for managing fire safety. Understanding the contribution of basic knowledge to fire technology represented in the system leads us to enhance the level of fire safety in our society.

There would be a number of issues to be resolved for fire safety in the future. Most of those issues will have arisen because of lack of basic knowledge on future of fires. Change will be in the dimensions and purposes of buildings and facilities. Also, the strategy and equipment for fire safety will change. Even the concepts for fire safety may change. Thus, phenomena expected to occur in the fires will change and knowledge on the phenomena that have been rarely observed in the past fires will be needed.

In such a situation, reliable knowledge will be of basic phenomena to occur in fires. There are so many basic phenomena useful for future fire safety that only a limited number of issues will be able to discuss in this paper. Thus, discussion is limited to knowledge to be needed for future fire safety on combustion, transfer phenomena, and aerodynamics. .

FIRE SAFETY MANAGEMENT SYSTEM

For effective fire safety management, we have to have a clear and reasonable concept for fire safety. An example of the fire safety management system is as follows:

1. A responsible individual or group for fire safety should make clear their policy to mitigate fire losses.
2. Based on the policy, the goal of fire safety program should be determined.
3. Appropriate planning for conducting the program has to be made.
4. Actions in the plan should be performed
5. Maintenance should be performed following a predetermined plan.
6. The system should be audited.
7. Improvement of the system should be performed whenever it is needed.

A responsible individual or group should determine all the processes in the system by negotiating with related persons, which include lower-class managers, workers, neighbors, and any others under influence of the management. The planning in the item 3 should be not inconsistent with all the related laws, regulations, and standards. All the actions for this system should be recorded and kept in files. The system is illustrated in Fig. 1.

COMBUSTION

Figure 2 shows combustion processes of typical combustible solids [3]. When wood pieces are burning as illustrated in Fig. 3, the solid thermally decomposes into combustible gas and burns in the air. In a usual fire, combustible materials are solids such as wood and plastics and composed of hydrogen, carbon, and oxygen or hydrogen and carbon. The combustion behavior of such combustible solids are much the same. Combustion products are mainly carbon dioxide and water at complete combustion and include intermediate species such as carbon monoxide and hydroxyl radicals. Although the reaction processes of those combustible solids have not yet been fully elucidated, the knowledge that we have at present

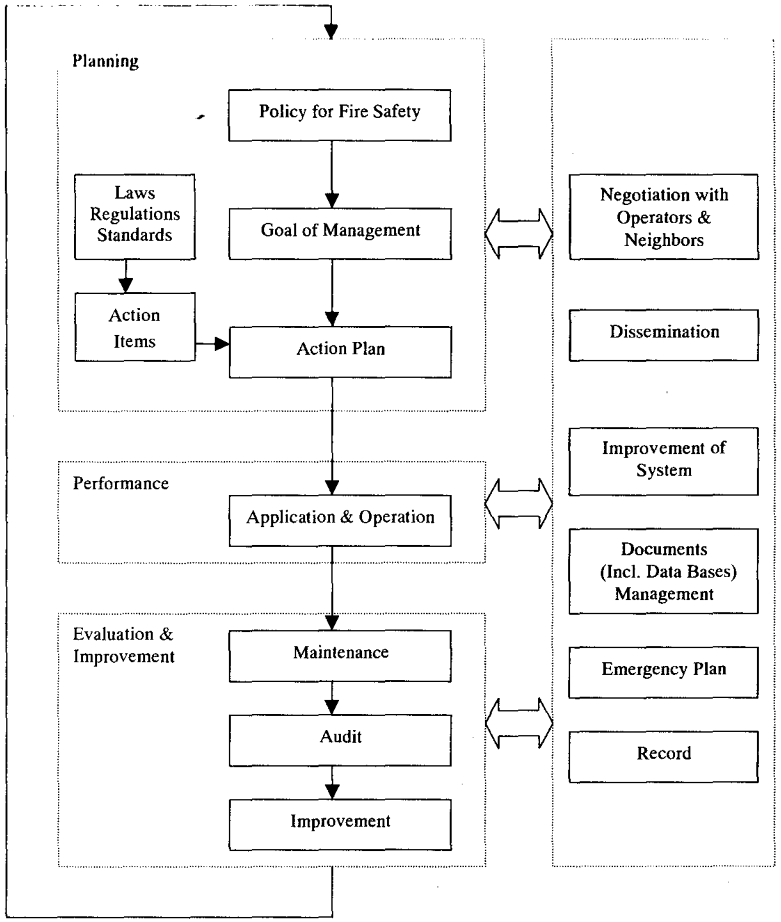

FIGURE 1. A fire safety management system

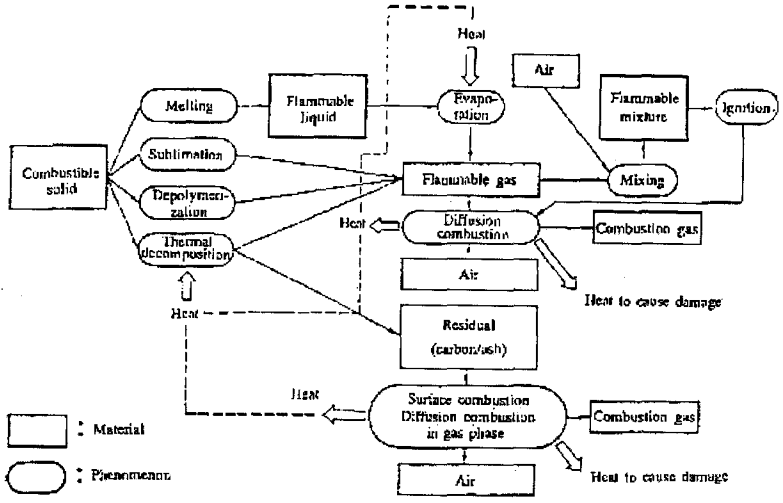

FIGURE 2. Combustion process of typical combustible solids [3].

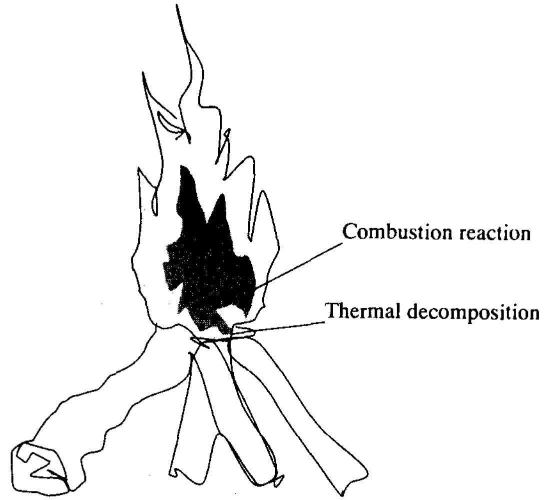

FIGURE 3. Combustion of wood pieces.

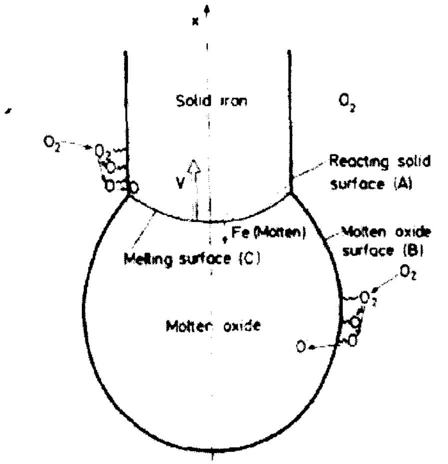

FIGURE 4. Description of the phenomena concerning fire spread along a mild steel cylinder [4].

is enough for performing the actions for fire safety.

The combustible materials to burn at fires depend on lifestyle at that time. Newly developed instruments and furniture will include new materials, and the manufacturing processes for those will be under novel type of fire hazards. We should accumulate needed knowledge for mitigating fire losses caused by such hazards.

It is almost impossible to predict what will happen in the future, so that we cannot indicate appropriate themes of the future studies in the field of fire science. However, there have been a number of studies having started for preventing a new type of hazards at a specific era in the past. When our group started studies on structural metal piece combustion, there was only primitive knowledge on the combustion mechanisms of structural metals. Before 1981, when we started studies on structural metal combustion, there were a number of oxygen compressor fires. In the factories, they realize the burning of structural metals in the atmosphere of oxygen. However, they could not find effective means to prevent the fires.

Our first paper on this subject was a review paper on metal combustion [4]. We summarize the knowledge obtainable at that time. Comparing the contents in the review paper to our later papers, you could find a large difference in the level of knowledge. There was only a poor model of combustion mechanisms. Fig. 4 shows the combustion mechanisms during combustion zone spread along an iron cylinder that we revealed only a year and half later [5].

At the annular solid surface (A) just above the molten mass, heat is released due to ion oxidation. The surface temperature must decrease as the distance from the boundary with molten mass increases. Also, at the molten oxide surface (B), oxygen is incorporated into the molten oxide mass. Across the boundary surface (C) between the molten mass and solid iron, heat released due to ion oxidation is transferred to the solid iron. Iron is melting at this surface (C) and mixing with the molten mass.

This mechanism is quite different from that believed in the past. The reaction at iron combustion had been believed to occur at the solid surface. In fact, the reaction that occurs at the molten mass surface is not main one. It is incorporation of oxygen into the molten mass after physical adsorption at the surface. The main reaction is inferred to occur in the molten mass, i.e., the combustion reaction in this case is a liquid phase reaction. The rate determining process of the combustion is heat transfer from the molten mass to the solid phase.

Throughout this experience, we realize that the most important matter for studies to reveal unknown facts is to accumulate knowledge about fundamental phenomena. I believe that most fire researchers have dealt with recent new type fires and relating equipment such as nuclear facility fires, semiconductor factory fires, high-rise building fires, automobile fires, evacuation systems, fire detectors, and gaseous extinguishers.

TRANSFER PHENOMENA

The fire damage is caused by heat released by combustion reaction, which depends on the concentration of reacting species and temperature at reaction site. The species concentration and temperature at the reaction site result from the mass and heat transfer. Thus, the mass and heat transfer phenomena are needed for understanding the behavior of fires. There are a number of examples to represent this.

Ignition is the first process at fire occurrence. A large number of studies have been carried out on this subject and the mechanisms of various types of ignition have been revealed [1-3, 6, 7]. Also, quantities representing ignition characteristics, such as ignition temperature, minimum ignition energy, and ignition delay time, have been evaluated or measured. A large number of data on this subject are available. Only when the phenomena are fully understood, however, the data are effective for developing or improving technologies for fire protection.

Ignition of most combustible materials in buildings, forests, or vehicles occurs in the gas phase. When a combustible solid of those materials is heated to a temperature above the gasification temperature, flammable gas starts to be ejected from its surface and mixed with air. Ignition occurs in this combustible gas-air mixture if the conditions of concentration and temperature of the mixture necessary for ignition are satisfied. The process of ignition can be found at the top part of Fig. 2.

The ignition of a flammable mixture occurs when the heat release rate is larger than the heat loss rate at any temperature below the flame temperature and the ignition process has been well discussed in previous studies [1-3, 6, 7]. The process depends mainly on the mixture composition. Since the mixture is composed of gas from a heated combustible solid and ambient air, the steps of gasification and mixing are important to understand the ignition in fires. In general, the heat necessary to ignite a flammable mixture is small compared to that necessary to gasify the solid combustible from which the combustible gas to compose the mixture is ejected. Also, the mixing of the gas with ambient air is necessarily under the influence of the buoyant gas flow near the heated surface.

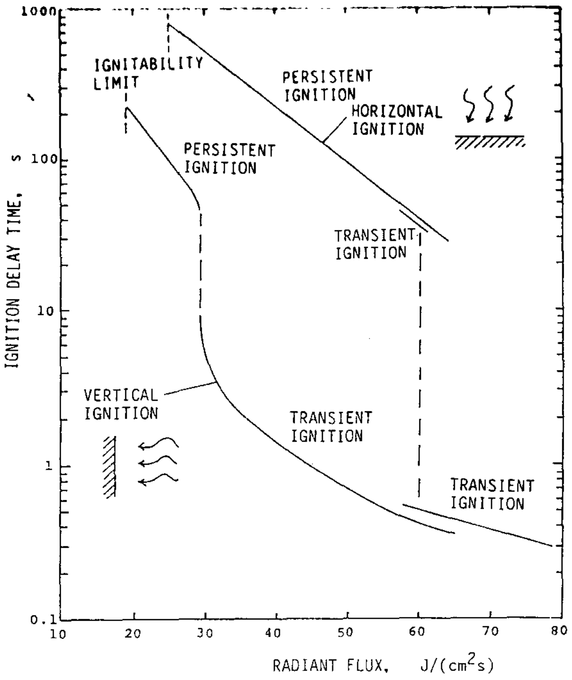

FIGURE 5. Ignition delay time at radiative ignition of PMMA piece [7].

Figure 5 shows measured ignition delay times of PMMA (polymethylmethacrylate) pieces under radiation [7]. The characteristics of each curve representing the variation of ignition delay time with radiant flux for horizontal and vertical surfaces are attributable to the resultant concentration and temperature distributions in each case. It is seen that the ignition delay time for persistent ignition at the horizontal surface is longer than that at the vertical surface. This difference is attributable to the difference of distributions of flammable gas concentration. For the horizontal surface, the point where the conditions to occur ignition are satisfied at first is at the periphery of the irradiated part, while for the vertical surface, it is at the bottom of the irradiated part. The latter case becomes easily under the conditions to occur ignition. For higher radiant flux, transient ignition occurs.

The jump of the ignition delay time at persistent ignition to that at transient ignition is caused by the mixture temperature increase at the top of the plume. For the persistent ignition, the conditions for ignition cannot be satisfied nowhere at the plume top and ignition occurs at the edge of the plume near the solid surface. On the other hand, for the transient ignition the conditions for ignition are satisfied at the plume top where ignition occurs.
The stage of a fire next to ignition is flame spread. Flame spread under various conditions has been examined and appropriate models have been proposed. The results of previous studies on this subject have been summarized in several review papers [4, 8-10]. The mechanisms of various types of flame spread have been explored and a large number of data have been accumulated. Studies on this subject seem to be the most advanced of those concerning fire development.

It is well known that the aspects of upward flame spread are much different from those of downward flame spread [9]. The flame, which spreads along a polymeric material, a typical combustible solid, is sustained by supplying combustible gas ejected from the pyrolysis region of the polymeric material surface. The rate of pyrolysis depends on the rate of heat transfer from the flame to the solid by conduction, convection and radiation. It is clear that these modes of heat transfer for upward flame spread are much different from those for downward flame spread. For upward flame spread the flame and hot gas stream covers the not-yet-pyrolyzing surface, while for downward flame spread the leading flame edge covers only a small portion of the not-yet-pyrolyzing surface. Thus, the rate of heat transfer to the solid for upward flame spread is much larger than that for downward flame spread, so that the rate of pyrolyzed gas ejection for the former case is much larger than that for the latter case. This is directly related to the observation that the rate of upward flame spread is in general much larger than that of downward flame spread.

The rate of flame spread can be expressed by the progress rate of the pyrolysis front. When the flame spread downward, heat transfer from the flame to the not-yet-pyrolyzing surface is confined near the leading flame edge. The phenomena may not depend on time, i.e., steady and we can obtain the flame-spread rate independent of time. It is well known that the flame-spread rate for a thin sheet is inversely proportional to the thickness, while that for a thick sheet is independent of the thicknes [9].

The examples described in this section as well as that in the previous section indicate that basic phenomena in fires strongly depend on transfer phenomena. Even in fires in the future, this situation will not change, so that for understanding novel types of fires, knowledge on transfer phenomena will be indispensable.

AERODYNAMICS

Transfer phenomena in the gas phase or at the gas-solid interface depend on gas flow, so that knowledge in the field of aerodynamics is the most effective to understand the phenomena in fires. This would be already realized in the previous section.

Figure 6 is an illustrative picture for explanation of the effect of induced gas flow to ignition at the wall heated by an external radiation source, which was described in the previous section. It is clear that the reactive species concentration and temperature are under influence of induced buoyancy flow at the heated wall.

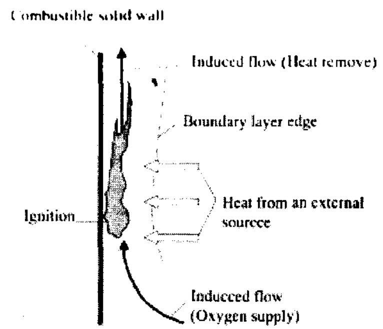

FIGURE 6. Aerodynamic effects on ignition

As mentioned in the previous section, the aspects of upward flame spread are much different from those of downward flame spread. The difference of the rates of downward and upward flame spread is attributable to that of the induced ambient gas flows. Only a breeze influences the flame spread (Fig. 7). The spread rate of the leading flame edge against the breeze slower than that in a concurrent direction. Understanding the gas flow in a fire is effective for reasonable prediction of fire development.

It is well known that behavior of a pool fire depends on its size [11-13]. The smoke behavior characterizes the behavior. For the pool size smaller than 1 m, the main part of the flame is reddish yellow in color, and smoke can be observed above the flame. Strong radiation comes from the whole flame. On the other hand, for that larger than a few meters, the plume except for small portions near its base and at a distance from the base is of heavy smoke consisted of soot (Fig. 8) [12]. The former appears continuously at a zone of a few meters from the base, and the latter appears intermittently at the center of the plume and moves upward.

In studies on the pool fires, the behavior of smoke has been extensively studied [12, 13]. It can be evaluated using the result shown in Fig. 8 that the smoke moves upward with a velocity about 15 m/s at a 30-m-diam-pool fire. However, there still remain a number of ambiguities about pool fires.

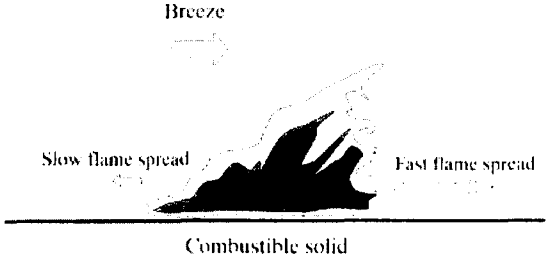

FIGURE 7. Effect of air flow on flame spread.

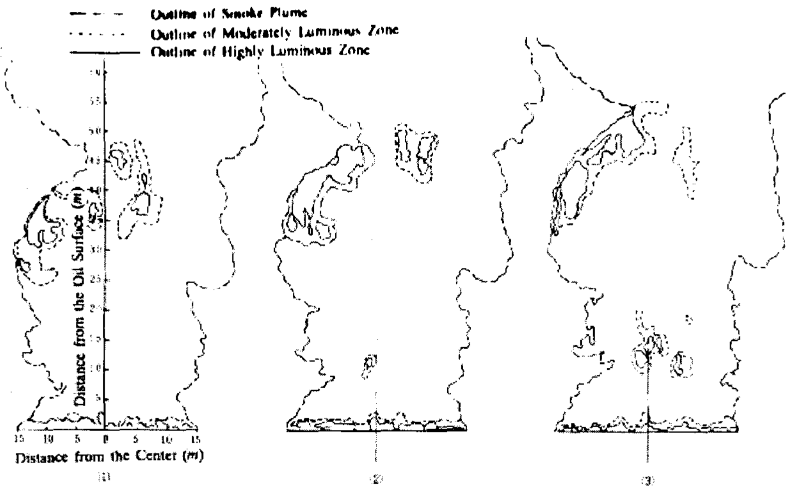

FIGURE 8. Shapes and movements of luminous parts observed at a 30-m-diam. model oil (kerosene) tank fire [12]. Upward velocity of luminous parts at the left hand side is about 16 m/s. (1) 271.67 s after ignition; (2) 271.67 + 1/3 s after ignition; (3) 271.67 + 2/3 s after ignition.

We often assume to be able to interpret a large-scale phenomenon on the basis of our knowledge accumulated by studying small-scale phenomena. Luminous parts are seen to appear at the outside of the black plume (Fig. 8). The researcher who observed this phenomenon would assume that the luminous parts are flames usually observed in small experiments. However, there is no evidence to infer the characteristics of luminous zone. The smoke can be observed at the point very close to the rim, where the average gas flow should be in the direction from out side to inside. The explanation of the process to generate smoke is not easy and we cannot define the characteristics of the luminous zone. The reasonable explanation of this phenomenon will become possible only after extensive studies on this subject by researchers having enough knowledge on aerodynamics, heat and mass transfer, and combustion reaction.

The aerodynamic aspects of large-scale phenomena are quite different from those of small-scale ones. If the temperature difference would be 30 °C, 1 meter in height of the plume may induce the gas velocity of 1 m/s. This means that without initial flow, gases in different temperatures likely compose layers. In such a case the mixing may occur only by molecular diffusion. Based on this knowledge, establishment of a high temperature layer beneath the ceiling in fire room can be explained.

This knowledge would be needed for fire detection and suppression. For fire detection and sprinkler operation by hot gas stream, detectors should be set at the points where hot gas is

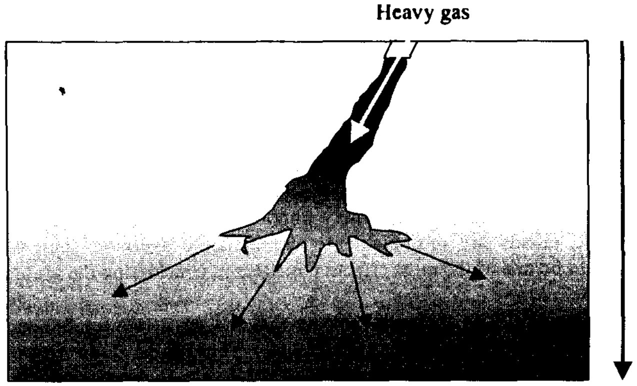

FIGURE 9. Layer establishment at heavy gas injection into a compartment.

likely to come.

For effective fire suppression by gas extinguishers, knowledge of aerodynamic aspects of the gas behavior is indispensable. To supply gas for extinguishing fires, the gas flow induced by gravity force should be predicted. If the gas density is a few percent larger than air the mixture of the gas and air moves to the floor. The velocity of each lump of the mixture depends on its size and gas concentration. Finally layers are established where the gas composition decreases with the distance from the floor. The fire occurred near floor can be suppressed by this type of gas extinguishers, while the fires occurred near ceiling cannot be suppressed.

In the future, a number of issues that seem hard to resolve may appear in the field of fire science. In such a case, the most effective ways to resolve must be the start from understanding of basic phenomena. Accumulation of basic knowledge is the best way for future fire safety.

CONCLUDING REMARKS

The aspects of fires depend on the manner of life at that time. Unfortunately, we cannot predict the future of our society. However, to mitigate fire losses in the future, we have to have effective means against fires beforehand. In this paper, a prospect of fire science in the future is presented, which is assumed on the basis of past experience.

The first step of preparation for mitigating future fire losses would be establishment of the fire safety management system. When one start to plan against fires, he would realize the importance of knowledge on basic fire phenomena.

The fire losses are caused by heat released by combustion. Every means to prevent a part of the process of combustion is effective for suppressing fires. When studies on new type of fires start, the most important knowledge is of basic phenomena concerning combustion.

The aspects of combustion are closely related to heat and mass transfer phenomena, which strongly depend on flow fields. A few well-known phenomena in fires are explained on the basis of knowledge about heat and mass transfer phenomena.

Knowledge in aerodynamics is extremely important for understanding phenomena in fires. Most of scale effects are attributable to aerodynamic aspects. The difference of gas densities would be one of the most effective matters in considering the scale effect.

A number of examples in the past indicate that the best way for future fire safety is to accumulate knowledge of basic fire phenomena. Thus, in the future fire science, basic fire phenomena will be main subjects to explore.

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On the Modeling of Forest Fires: from Physical Background toward Practical Output

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ABSTRACT

The problem of elaboration of the system for forest fire behavior prediction is considered including the formulation of fire spread mathematical model based on the radiation heat transfer mechanism, classification of natural fuels using the forest inventory data, approximation of fire perimeter propagation, programming realization of fire simulation code and overall arrangement.

KEYWORDS – Forest fire, Fire spread model, Flame radiation, Forest fuel, Computer simulation, Fire behavior system

NOMENCLATURE

C - Specific heat of fuel;
D - Width of burning zone;
H - Flame height;