

An Experimental Study on the Characteristics of Sodium Fires

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나트륨 화재 특성의 실험적 연구

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Abstract

A sodium fire facility with a test chamber of 1.7m³ volume was constructed and operated to carry out experiments of sodium fires such as pool, spray, and columnar fires which might take place in sodium-related facilities.

The experimental results of pool fires showed that the increase of temperature and pressure in the test chamber was much smaller than that of spray and columnar fires even though their amount of sodium injection in the chamber was much larger compared to other types of fires. And it was found in pool fires that the temperatures of sodium pool and the gas temperature in the test chamber had been maintained much longer than other types of fires, and that the chamber pressure had come to vacuum due to depletion of the oxygen for a large amount of sodium injection in the chamber.

The experimental results of spray fires showed that sprayed sodium of small particles instantly reacted with oxygen, and that its reaction heat increased gas temperature and pressure of the test chamber rapidly and decreased them shortly. And the maximum gas temperature and pressure of the test chamber in spray fires were greatly changed according to the inlet sodium temperature in the test chamber.

The characteristics of the columnar fires were almost similar to those of spray fires, but the maximum temperature and pressure of the test chamber were much smaller even for a large amount of sodium injection. And it was shown in spray and columnar fires that the temperatures at each measurement position in the test chamber were quite different due to the instantaneous sodium oxidation in comparison with pool fires.

Finally, the graphex powder was proved to be a very effective extinguisher against sodium pool fires.

요 약

시험용기가 1.7m³가 되는 소규모 나트륨화재 실험 시설을 건설하여 나트륨 관련시설에서 발생가능한 풀형화재, 분무형화재, 그리고 원주형화재와 같은 나트륨화재 실험을 실시하였다. 그 결과 풀형화재는 나트륨 주입량에 비하여 온도 및 압력 증가치가 분무형화재와 원주형화재보다 훨씬 작지만 상당기간 나트륨풀과 용기안의 온도를 높게 유지시키며 나트륨 주입량이 많을 경우 용기내의 산소를 거의 소모시켜 용기안의 산소농도를 0mol%에 근접시키고 진공 상태까지 이르게 하였다. 분무형화재는 분산된 작은 나트륨이 순간적으로 산소와 반응하여 급격히 용기내의 온도와 압력을 증가시키며 곧 감소하였다. 분무형화재의 최고 도달온도와 압력은 초기 산소농도 그리고 나트륨 주입온도에 따라 크게 차이를 보여 주었다. 원주형화재는 분무형화재와 거의 유사하지만 좀 더 많은 양의 나트륨을 시험용기내에 주입시켜도 최고 도달 온도와 압력이 분무형보다 작았다. 그리고 분무형화재와 원주형화재에서는 풀형화재에 비하여 순간적으로 분산된 나트륨이 산화하여 용기내의 측정위치에 따라 온도분포가 크게 차이를 보여주었다. 끝으로, 풀형화재 소화실험에서는 소화제 graphex가 효과적으로 나트륨 화재를 진화시킬 수 있음을 확인하였다.

1. Introduction

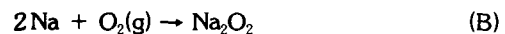
The physical properties of liquid sodium make it a suitable material for the heat transfer fluid of the present generation of fast breeder reactors (FBR). However, particular disadvantages of liquid sodium are its chemical reactivity with oxygen and water in the atmosphere. At temperature of interest to the operation of the reactor, most spillages of liquid sodium can be expected to result in fire since the containment is usually not inert. An extensive study of the burning of sodium has been actively carried out in the United States, France, Germany and Japan which have been concerned with FBR development. These studies have covered basic aspects, the burning of sodium in various physical forms and the effect of scale on sodium fires. They were reviewed previously [1, 2].

In sodium-related facilities three main types of sodium fires are recognized, namely, pool, spray and columnar fires, which have distinctive combustion behaviour and damage potential characteristics. Pool fires are characterized by a low flame burning on the pool surface with copious release of dense white 'smoke'. With large systems there is potential for large pool fires of many tens of square meters area and hundreds of mm depths. Spray fires result from

a release of sodium at high pressure, sufficient to eject it as a spray of droplets. And the sprayed sodium is assumed to burn instantaneously with rapid release of heat and oxygen consumption. As a kind of combined fires of pool and spray, columnar fires resulted from undisturbed downward jet flow of sodium, generation of sodium droplets on the floor, and their instantaneous burning around the accumulated sodium pool at the bottom of the test chamber. In all these fires sodium burns to form two possible oxides and generate heat in the following reactions:



$$\Delta H_{298^\circ\text{K}} = -104,000 \text{ cal/mol}$$



$$\Delta H_{298^\circ\text{K}} = -124,000 \text{ cal/mol}$$

The relative portions of these oxides will vary with the temperature of combustion and the relative portions of oxygen and sodium. And the oxide fume from a sodium fire in air is considered to be Na₂O, Na₂O₂, or mixture of them.

The sodium handling technology is an essential part of FBR development for the reactor coolant safety. This technology can be acquired by operation of sodium fire facilities and analysis of experimental

results. As a part of accumulation of sodium safety technology for FBR development in Korea, a sodium fire test facility was constructed and operated in Korea Atomic Energy Research Institute. This paper describes the sodium fire test facility and presents some of the experimental results of various sodium fires and their extinguishment which have been operated in the facility.

2. Sodium Fire Facility

Sodium leakages from FBRs and sodium loop facilities may lead to three different types of fires with different consequences. These are pool fires, spray fires, and columnar fires which occur in different leaking conditions. In this work, a sodium fire facility was specially designed and built to study characteristics of various sodium fires which might take place in the sodium-related facilities. The facility consists of a cylindrical test chamber, a sodium reser-

voir tank, a sodium supply tank, a drain tank, a gas control system, a fire extinguishing system, a data acquisition system, a control panel, a sampling system, a steam generator, and gas supply system which are briefly shown in Figure 1.

2.1. Test Chamber

The test chamber is a core part of the sodium fire experimental facility. It was designed to make various sodium fires which might take place in the sodium-related facilities and to observe them through the eyeglasses of the chamber.

The test chamber is a gastight stainless steel container of 1.7m³ volume; the cylindrical part of the chamber is 1.8m in height and 1.2m in diameter. The drain tank under the test chamber was designed to collect the wastes of sodium fire products which might be deposited on the inside wall of the chamber during sodium fire experiments. These fire products

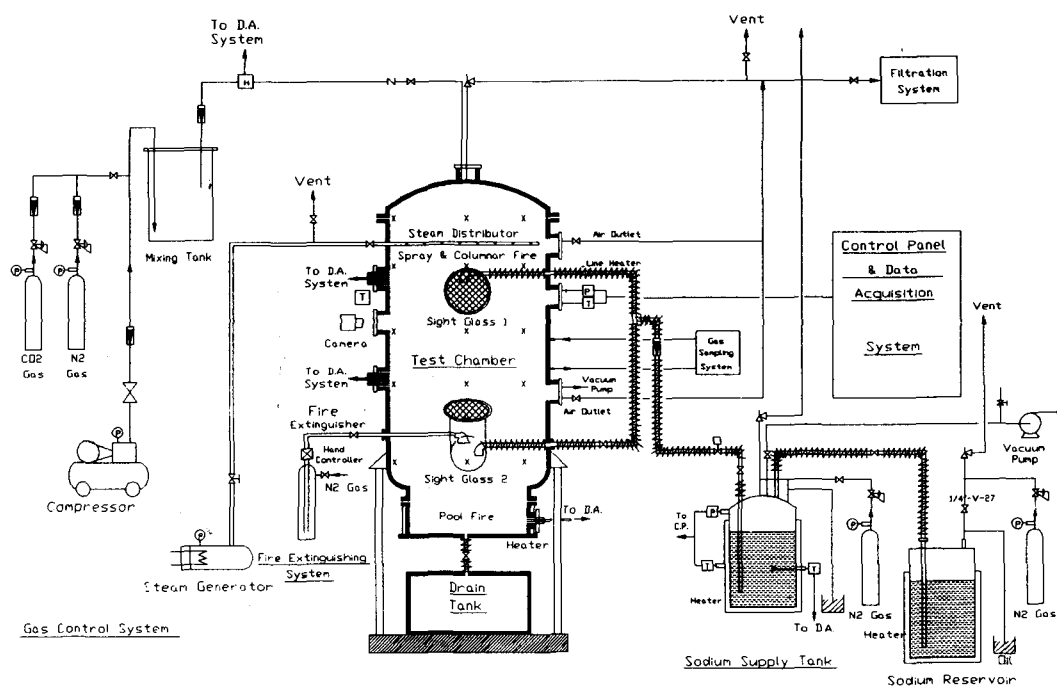


Fig. 1. Flow Diagram of Na Fire Facility

could be washed out by steam injection in the chamber after fire experiments.

2.2. Gas Control System

Sodium fires might take place under various oxygen environments in the sodium-related facilities. And they need to carry out under the different oxygen conditions in sodium fire experiments. After sodium fire experiments it may also be necessary to evacuate the chamber and to fill up nitrogen in it in order to perform steam cleaning of unreacted sodium and sodium fire products in the chamber for prevention of hydrogen explosion. Thus, the gas control system was set up to control oxygen and nitrogen concentration in the test chamber for sodium fire experiments. In this system, air was supplied by a compressor, and nitrogen was injected from a nitrogen cylinder. The two fluids were controlled by flow meters, mixed in a mixing tank and fed in the test chamber under a certain experimental concentrations of oxygen in the range of 0 to 21 mol%.

2.3. Sodium Supply System

The sodium supply system consists of a sodium reservoir tank, a sodium supply tank, nitrogen supply and control section, sodium transfer and supply piping section, and vacuum pump. The sodium reservoir tank is a cylindrical drum with 190Kg sodium capacity which was purchased from the Metaux Speciaux S.O. in France. Three band heaters and thermocouples were installed around the reservoir tank to heat and control its temperature for sodium transport to the sodium supply tank.

The sodium supply tank of 0.5m in height and 0.4m in diameter was designed to supply sodium to the test chamber at a certain experimental temperature. Three immersion heaters and two thermocouples were installed in the sodium supply tank to heat and control sodium temperature. Three

level indicators which were made from automobile spark plugs were also positioned in the tank. These level indicators only give a light signal when the level of liquid sodium in the tank rises to the position of each plug which are 2, 10, 25cm meter above from the bottom of the supply tank. Nitrogen was filled as an inert gas in the upper part of the sodium supply tank. Heating tapes and thermocouples were instrumented around the sodium transfer and supply piping section to maintain sodium temperature.

2.4. Control Panel and Heating System

In order to operate the sodium fire facility safely and efficiently, the heating system of sodium tanks and the piping sections was designed to control their temperatures under certain experimental conditions by a control panel. The control panel, which is located at a little away from the fire facility, indicates temperatures of heating systems (sodium storage and supply tanks, sodium transfer and supply piping system) of the test chamber and sodium tanks. It also indicates pressure, oxygen concentration, humidity in the test chamber and sodium level in the sodium supply tank.

2.5. Data Acquisition System

This system is to measure pressure and temperature, oxygen concentration and other values in the test chamber, and to store them in the computer memory during sodium fire experiments, for the analysis of sodium fire characteristics later. The signals from the sensors of pressure transducer, thermocouples, oxygen meters, moisture analyzers, and sodium flow meter were sampled by a measurement and control system of Keithly DAC 500A which was controlled by a microcomputer as shown in Figure 2. Table 1 lists the input signal status in each channel of the modules in the measurement and control system. The thermocouples of K-type to measure temperature distribution in the test chamber

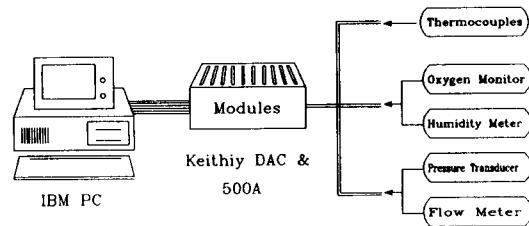


Fig. 2. View of Data Acquisition System

were installed as shown in Figure 3.

2.6. Sodium Fire Extinguishing System

This system consists of a powder extinguisher cylinder, a nitrogen cylinder with a gas regulator, and piping section. The powder extinguisher cylinder was modified from a commercial ABC powder extinguisher to study the characteristics of sodium fire extinction. The injection speed of extinguishers was controlled by the gas pressure regulator.

3. Sodium Fire Experiments

Before starting experiments, first of all, it is necessary to confirm the proper operation of control panel,

data acquisition system and measurement instruments, and to check the function of the safety system of the sodium fire facility. After confirmation of proper operation of all systems and instruments of the facility, various experimental conditions of sodium fires were then adjusted. The initial oxygen

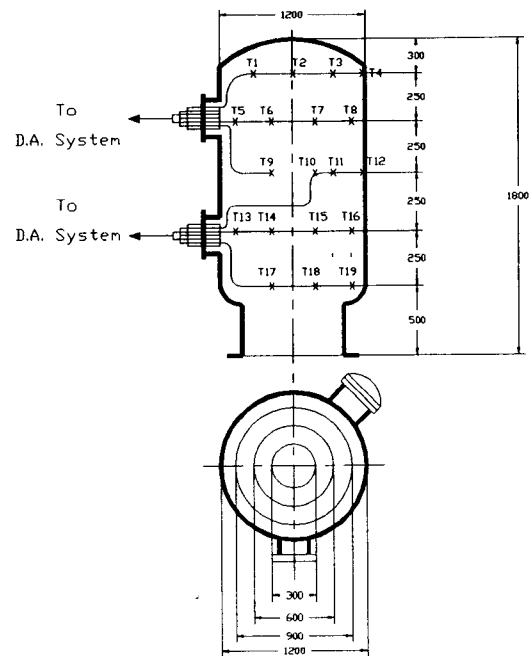


Fig. 3. Thermocouple Configuration of Test Chamber

Table 1. Input Sensor Status of Data Acquisition System

Module (slot)	Channel	Output	Input	Measurement Parameters
AMM2(1)	0	O ₂	0-10V	Oxygen concentration of test chamber
	1	DEW	2-10V	Moisture of test chamber
AIM5(3)	0	PV	0-36mV	Pressure of test chamber
	1	PO	0-36mV	Pressure of sampling system
	3	PS	0-36mV	Pressure of sodium storage tank
	4	FNA	0-10mV	Flow rate of sodium
AIM7(4)	0	TC1	...	Cold junction
	1~15	TV 1~15	0-52mV	Temperature of test chamber
AIM7(7)	0	TC2	...	Cold junction
	1~4	TV16~19	0-52mV	Temperature of test chamber
	5	TP1	0-52mV	Temperature of burning pan
	6	TNA	0-52mV	Temperature of sodium inlet tube

concentration of the test chamber was controlled by the gas control system and the inlet sodium temperature of sodium fires was regulated by the sodium supply tank through the control panel. Special conditions of pool fires, spray fires and columnar fires were also fixed, respectively. Sodium fire experiments were started by injecting liquid sodium into the test chamber. Temperature, pressure, and oxygen concentrations of the test chamber were measured through the data acquisition system during the experiments of sodium fires so as to analyze the characteristics of sodium fires later.

In case that there was not enough sodium in the sodium supply tank, which could be discerned by the sodium level lamp in the control panel, sodium in the reservoir tank was to be transferred to the sodium supply tank by nitrogen pressure of 5 psi after its melting. It almost took 8 hours to heat and melt sodium in the reservoir tank for its transport to the supply tank. All the experiments of sodium fires in this work were carried out in a confined atmosphere. And nitrogen gas was filled up in the sodium transfer and supply piping section before sodium transport to the test chamber for prevention of sodium clogging in the pipe section. Details of experimental procedure are found elsewhere [1].

3.1. Pool Fires

Sodium pool fires take place when sodium is leaked in the sodium-related facilities, formed as a

sodium pool at the bottom of the container, and reacts with oxygen in the container. In order to simulate sodium pool fires by experiments, a burning pan was installed at the bottom of the test chamber and a sodium fire was generated by injecting liquid sodium on the pan in the chamber. The main parameters of sodium pool fires have been known to be the temperature of sodium pool, the amount of injected sodium, and the initial oxygen concentration of the test chamber [3, 4]. And the characteristics of pool fires can be described by change of temperature, pressure and gas composition in the container [3]. In these fire experiments the burning pans of 15 to 30 cm² were used and sodium of 0.8 to 4.5kg was injected in the test chamber. The sodium inlet temperature was 300°C. The main experimental conditions are shown in Table 2.

3.2. Sodium Spray and Columnar Fires

Leakages of pressurized liquid sodium through pipe crack can lead to sodium sprays. In normal atmosphere the sprayed sodium will immediately ignite and result in a sodium spray fire. And sodium may fall downward in the form of a column due to the presence of leak jackets, make a pool generating droplets around the floor, and result in a columnar fire in normal atmosphere.

In order to perform the sodium spray and columnar fires, a sodium ejection device consisting of a nozzle and piping section for sodium injection was

Table 2. Experimental Conditions of Pool Fires

Test No.	Pan dia. (cm)	Initial O ₂ conc. (%)	Sodium quantity (g)	Sodium temp. (°C)	Chamber volume (m ³)	Pan depth (cm)
P15-1	15	19.5	800	230	1.7	5.0
P15-2	15	10.8	1,400	220	1.7	9.0
P30-1	30	19.0	4,100	230	1.7	6.5
P30-2	30	15.5	4,500	235	1.7	7.0
P30-3	30	11.5	3,800	220	1.7	6.0

Table 3. Experimental Conditions on Spray and Columnar Fires

Test no.	Spray nozzle			Sodium injection			Initial O ₂ conc. (%)
	Angle (°)	Dia. (mm)	Temp. (°C)	Press. (psig)	Mass (g)	Time (sec)	
SP-1	50	1.2	330	37	120	6	19.9
SP-2	50	1.2	305	37	120	6	19.6
SP-3	50	1.2	275	37	120	6	19.8
SP-4	50	1.2	205	37	120	6	19.7
COL-1	0	1.0	300	29	300	20	20.2
COL-2	0	1.0	300	29	300	20	10.0

installed 1m vertically above a burning pan in an axis symmetric way inside the test chamber. The nozzle direction was downward with its diameter of 1.2mm and 1.0mm and its spray angle of 50° and 0° for spray and columnar fires, respectively. The main parameters of sodium spray and columnar fires have been known to be the inlet temperature of sodium, the amount of injected sodium, injection speed and time of sodium, and gas composition of the containment [3, 5]. And the characteristics of spray and columnar fires can be described by change of temperature, pressure, and gas composition of the test chamber similar to sodium pool fires [3, 5]. The major experimental conditions of spray and columnar fires are shown in Table 3.

3.3. Extinction of Sodium Pool fires

There are two means of sodium fire extinction which have been developed in the United States, France, Japan, Germany and the United Kingdom. These are the passive means of extinction, which consist of smothering tanks and funneling floor with pipes for sodium recovery, and the active means using extinction powders such as graphex and marcalina. In this experiment, the latter method was chosen for extinction of sodium pool fires. The selected extinction powder was graphex.

The graphex has been developed in the CEA of France. This extinguisher is based on carbon powders. It is reported that at high temperature the

graphex forms uniform and continuous coating on the metal surface which restricts the diffusion of oxygen towards the sodium surface and results in fire extinction [6]. The experimental conditions of sodium fire extinction are shown in Table 4.

Table 4. Experimental Conditions of Sodium Fire Extinctions

Pool fire
◦ Pan diameter: 30cm
◦ Sodium injection
— Temperature: 230°C
— Quantity: 4000g
— Flow rate: 200g/sec
◦ Initial O ₂ conc.: 20%
Pool fire Extinguishment
◦ Extinguisher: Graphex CK.23
◦ Injection
Quantity: 500g
— N ₂ pressure: 65psi
— Flow rate: 100g/sec
— Starting time: 50 seconds after sodium injection

4. Results and Discussion

4.1. Pool Fires

The phenomena of pool fires in this experiment were observed in the sight glass of the test chamber. As soon as the hot liquid sodium was injected in the

chamber and formed a pool on the pan at its bottom, the sodium pool fire of orange color occurred and the fire regions were further expanded. Then sodium aerosols of white color increased rapidly and the inside of the test chamber could not be seen by eyes any more.

The temperature changes of sodium pool and gas caused by pool fires in the test chamber are shown in Figures 4 and 5. The maximum temperature of sodium pool was 510°C for initial oxygen concentration of 19% after 1200sec. But for initial oxygen concentration of 11.5% it was much lower temperature of 375°C after 1800sec. This indicates that the higher initial concentration of oxygen expedites the burning rate of sodium and approaches the maximum temperature of sodium pool more rapidly. And it is concluded in pool fires that high oxygen concentration of gas in the chamber expedites the sodium combustion and that the heat generated by its combustion increases the temperature of sodium pool.

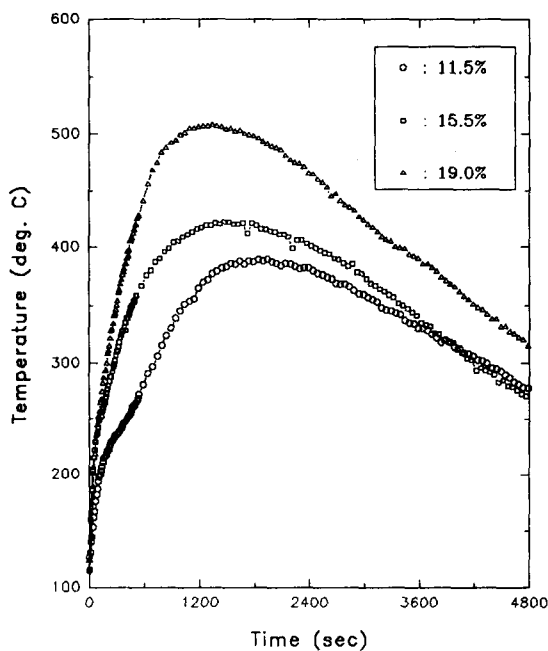


Fig. 4. Temperature Change of Sodium Pool (Dia.=30cm) in Pool Fires as a Parameter of Initial Oxygen Concentration.

The gas temperature of the test chamber also increased along with increase of its initial oxygen concentration, but the extent of the temperature increase was not high compared to sodium pool temperature and there was not any close relationship between the sodium pool temperature and the gas temperature of the test chamber. This result is possibly due to slow heat transfer in the gas phase and difference of injected amount of sodium in the test chamber for three initial oxygen concentrations.

The change of pressure and oxygen concentration of the test chamber is shown in Figures 6 and 7. After sodium injection, the pressure of the chamber increased fast, approached the maximum pressure, and decreased slowly. But the maximum pressure of the chamber for pool fires was very low and the chamber pressure was reduced to zero or vacuum after the maximum pressure was reached. These phenomena can be analyzed as follows: The maximum theoretical amount of sodium needed for its complete combustion in this closed chamber of 1.

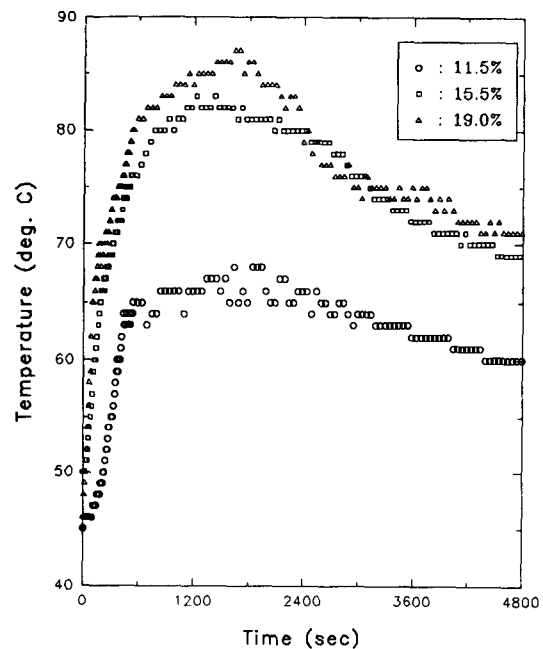


Fig. 5. Change of Average Gas Temperature in the Test Chamber in Pool Fires (Pool Dia.=30cm) as a Parameter of Initial Oxygen Concentration.

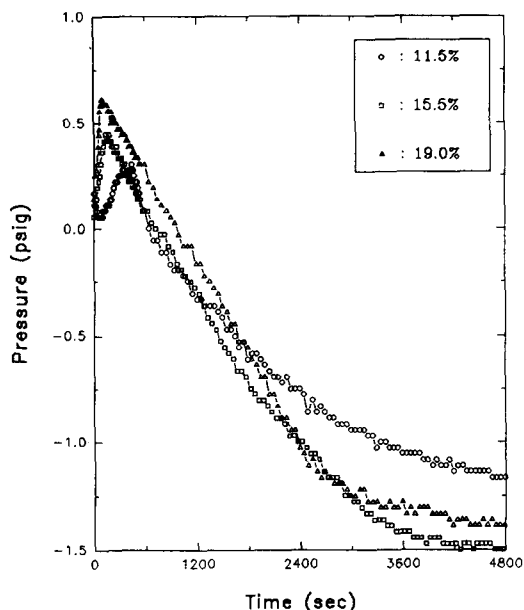


Fig. 6. Change of Gas Pressure in the Test Chamber in Pool Fires (Pool Dia.=30cm) as a Parameter of Initial Oxygen Concentration.

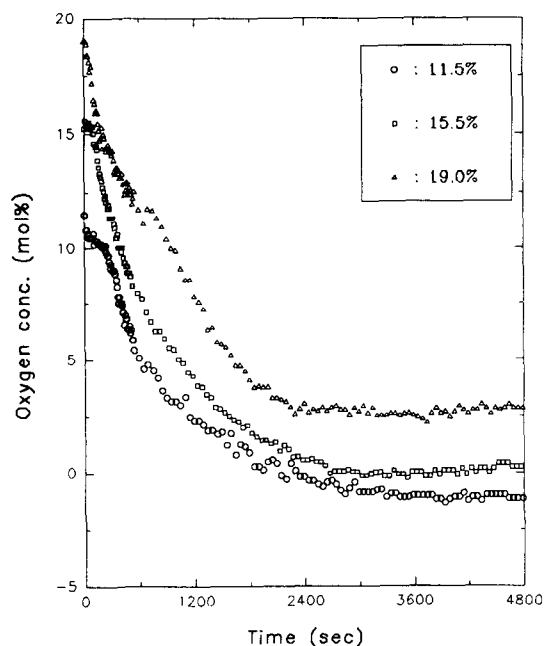


Fig. 7. Change of Gas Pressure in the Test Chamber in Pool Fires (Pool Dia.=30cm) as a Parameter of Initial Oxygen Concentration.

7m³ is estimated to be 665-1330g which depends on its sodium combustion product (Na_2O_2 , Na_2O). Thus, the amount of injected sodium on a burning pan of 30cm² in these pool fire experiments as listed in Table 3 seemed to be too much for complete fires. And the large decrease of the chamber pressure in the sodium pool fires is analyzed to be due to oxygen consumption by its reaction with sodium in the chamber during pool fires, and to gas cooling after fire extinction. The oxygen concentrations of the test chamber were reduced for all experimental conditions and approached zero for the initial oxygen concentrations of 15.5% and 11.5% as shown in Figure 7. Thus the fire extinction seemed to occur when no more oxygen for its reaction with sodium was present in the chamber or a great deal of combustion products were generated on the sodium pool to prevent oxygen diffusion in it.

The experimental results which were obtained with use of a smaller burning pan of 15cm² were similar to those for a larger size of sodium pool (30cm²) and more injection of sodium except lower increase of gas temperature and pressure of the test chamber.

4.2. Spray and Columnar Fires

In spray fire experiments, hot liquid sodium was dispersed in the test chamber through a nozzle with spray angle of 50°. Bright flames of orange colors were observed just below the nozzle while the sodium was falling to the bottom floor of the chamber. Ten seconds after sodium injection the inside of the test chamber could not be observed due to generation of a great deal of sodium aerosol. And the fire products on the floor of the test chamber were found to consist of precipitated aerosols of sodium oxides.

Figures 8 and 9 show change of average gas temperature and pressure in the test chamber for spray fire experiments. In this experiment the liquid sodium of 120g was injected in the chamber with a rate of 20g/sec. The temperatures of liquid sodium which was controlled in the sodium supply tank were 205,

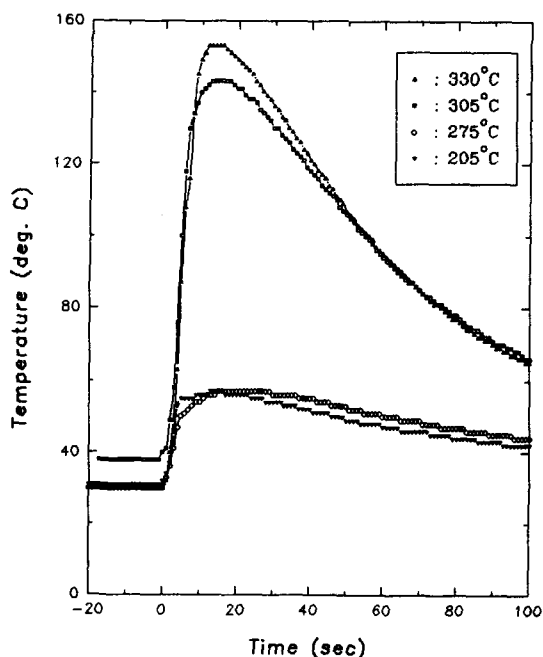


Fig. 8. Change of Average Gas Temperature in the Test Chamber in Spray Fires as a Parameter of Inlet Temperature of Sodium.

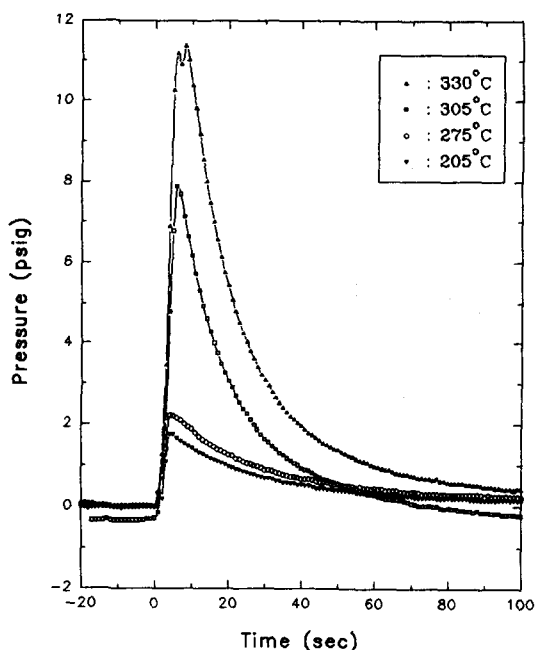


Fig. 9. Change of Gas Pressure in the Test Chamber in Spray Fires as a Parameter of Inlet Temperature of Sodium.

275, 305, and 330°C. As shown in the figures, the average gas temperature and pressure in the test chamber for spray fires increased rapidly to maximum points possibly due to plenty of combustion heat caused by rapid oxidation of tiny sodium particles which have large surface area in comparison with pool and columnar fires. The maximum gas temperature and pressure in the chamber for the inlet sodium temperature of 330°C was 155°C and 11.5psi, respectively.

In spray fires the sprayed sodium of small particles is thought to violently react with oxygen, produce Na_2O_2 or Na_2O , and generate its reaction heat which causes to increase the temperature of the test chamber. And as shown in Figures 8 and 9, the maximum gas temperature and pressure of the test chamber increased as the inlet temperature of liquid sodium increased. It is noticeable that increase of gas temperature and pressure in the test chamber was much bigger in the higher inlet temperatures (305 and 330°C) of sodium than in the lower ones (205 and 275°C). This can be explained as follows: Below 300°C, sodium monoxide(Na_2O) is mainly formed and a small heat of reaction is generated as shown in equation (A) [7]. Above 300°C, sodium peroxide(Na_2O_2) is formed with oxygen in excess, and larger reaction heat is generated in equation (B), which causes to increase the gas temperature and pressure of test chamber much higher.

Figure 10 shows change of the temperature distribution at the three locations of T10, T15 and T18 in the test chamber which are drawn in Figure 3. The location of T10 was located outside the spray region, and the locations of T15 and T18 were in the spray region. The temperature of the latter two locations increased to maximum points more rapidly and decreased fast compared to the one of the former location. These results indicate in spray fires that the dispersed sodium is instantaneously reacted with oxygen at the spray region of the test chamber and formed a fire flame, and increased the temperature rapidly. And the fire products of sprayed sodium

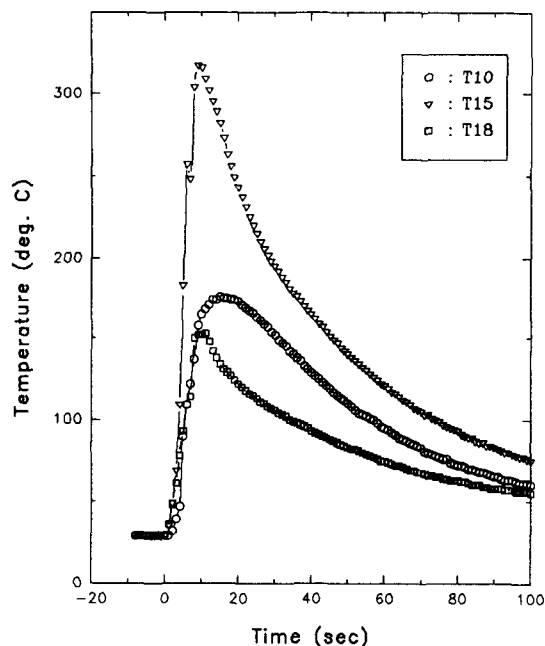


Fig. 10. Change of Temperature Distribution in the Test Chamber in Spray Fires as a Parameter of Measurement Location; Na Injection Temperature=330°C.

seemed to disappear in the sprayed region shortly after sodium spraying and fell down to be accumulated at the bottom floor of the test chamber.

In columnar fire experiment liquid sodium of 300g was injected in the test chamber through a spray nozzle of zero degree at a rate of 15g/sec by nitrogen pressure of 29 psi. The injected sodium was designed to fall down to the floor as a columnar form, to produce a sodium pool on the burning pan, and to generate a little flame of sodium combustion around the floor. The maximum pressure was 4.5 psi and 2.7 psi for the initial oxygen concentration of 20% and 10%, respectively. This pressure was lower than the one in spray fires, and much higher than the one in pool fires. And the time to attain the maximum pressure was less than 5sec which was shorter than the sodium injection period of 20sec as shown in Figure 11. It was noticeable in columnar fires that the gas pressure of the test chamber did

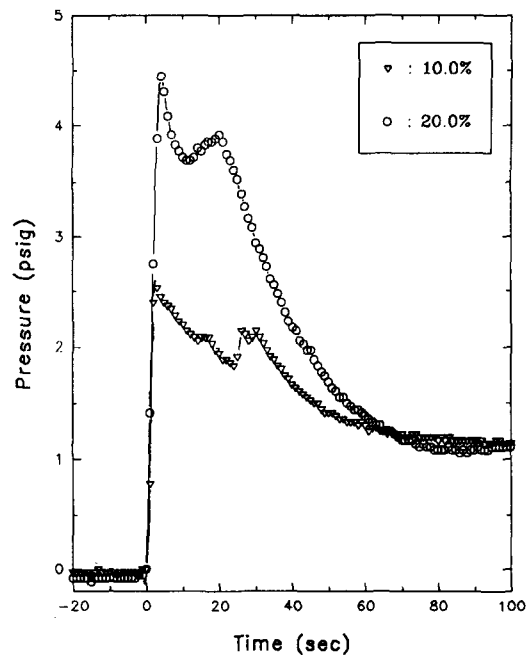


Fig. 11. Change of Gas Pressure in the Test Chamber in Columnar Fires as a Parameter of Initial Oxygen Concentration.

not decrease monotonously. These characteristics can be analyzed as follows: Most part of injected sodium fell down on the floor of the test chamber as a columnar form. But a little part of the sodium was sprayed around the nozzle while it was falling down to the floor and reacted with oxygen rapidly, which caused to increase the gas pressure in the test chamber and to produce the first peak pressure. The second peak of the gas pressure is thought to be caused by ignition of splashed sodium which was accumulated on the floor.

Figure 12 shows change of the temperature distribution at three locations in the test chamber for columnar fires. The measurement locations of T10, T15, and T18 are the same as the spray fire experiments. As the measurement position of the temperature was closer to the floor in the test chamber, its temperature became higher in contrast with the spray fire. This is implied that columnar fires

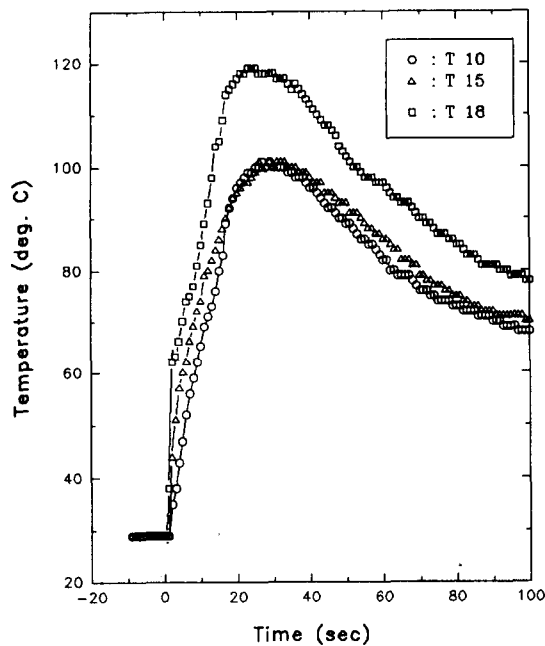


Fig. 12. Change of Temperature Distribution in the Test Chamber in Columnar Fires as a Parameter of Measurement Location; Initial Oxygen Concentration=20%.

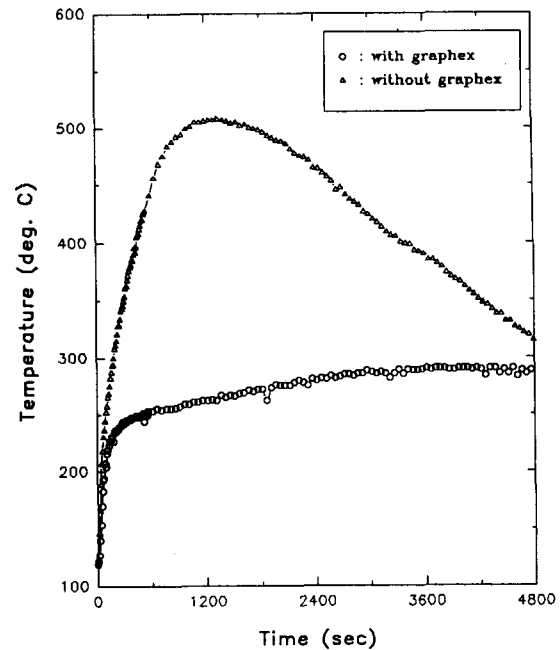


Fig. 13. Temperature Change of Sodium Pool With or Without use of Graphex Powder Extinguisher in Pool Fires.

mainly take place on the floor.

4.3. Extinction of Sodium Pool Fires

Extinction experiments of sodium fires were carried out by spraying graphex powder on the sodium pool of 4000g after its ignition. Initially the fire flames of pool fires were generated in a little part of sodium pool and were spread to its entire section after 50sec. When the graphex powder of 500g on the burning pan of 30cm² was sprayed at this point, no flames were observed and fire extinction was accomplished at once. Figure 13 shows the temperature change of sodium pool for a pool fire with or without use of a graphex powder at the same experimental conditions. As shown in the figure, the graphex powder extinguisher reduced the maximum temperature of sodium pool by more than 200°C in addition to extinguishing the pool fire at once in

comparison with no use of the extinguisher. This proves that the graphex powder used in this experiment is an effective extinguisher for sodium pool fires as proposed in AECF 500[6].

5. Conclusion

A sodium fire facility was designed, constructed, and operated to simulate sodium fires which might take place in sodium-related facilities. The cylindrical test chamber which is the core part of the facility was designed to be 1.8m in height and 1.2m in diameter. In this chamber three different types of fires such as pool fires, spray fires and columnar fires were generated under various experimental conditions of initial oxygen concentrations and inlet temperatures of sodium in a confined atmosphere.

Pool fire experiments show that the increase of temperature and pressure in the test chamber was

not high in comparison with spray and columnar fires. However, it was noticeable in pool fires that hot temperatures of sodium pool and gas in the chamber had been maintained for a quite long time and that the chamber pressure had come to vacuum due to mainly oxygen consumption by sodium oxidation. Spray fires were evaluated as the most dangerous fires since the increase of gas temperature and pressure were found to be the highest among all types of fires even though a small amount of sodium was injected in the chamber. Columnar fires were shown to have two peaks of gas pressure in the chamber. It was inferred that their first peak was formed by a little sodium combustion during its injection and that the second peak was due to oxidation of splashed sodium on the floor.

Finally the graphite powder was proved to be an effective extinguisher to put out sodium pool fires by this experiment.

Further studies of sodium fires including analysis of sodium aerosol are recommended to develop the sodium fire models for application of safety analysis of FBR coolant.

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