EXPERIMENTAL STUDY OF BOILOVER PHENOMENA IN OIL FIRES

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ABSTRACT

An experimental study has been made on boilover phenomena in oil pool fires with water sublayer. The objective of this research effort is to improve our understanding for physical characteristics of the boilover process, and to explore a new way for detecting and predicting the occurrence of boilover.

The fire behavior of boilover process is examined for different oil types. Local temperature histories of oil-water sublayers during the burning progress are measured. The characteristics of combustion noise to boilover process are analyzed in time and frequency domains.

1. INTRODUCTION

Once the occurrence of boilover in oil tank fires, safety accidents will be seriously escalated. Therefore, how to detect and to prevent hazardous occurrence of the boilover, that is of great concern.

The early work on the study of boilover phenomena has been focused more attention on the condition under which boilover occurs.[1][2][3] Hall first presented the concept of an isothermal layer or a so called hot zone be formed in the burning liquid. In a recent study Hasegawa[4] extended Hall's idea on hot zone. An experimental study[5] of boilover in connection with crude oil and kerosene pool fires was carried out in the large scale test facilities. The maximum intensity of burning was found to be related to the hot zone thickness and to the initial fuel thickness. M. Arai and K. Saito, etc.[6] have performed a series of laboratory-scale pool fire tests, and studied fundamental aspects of the effect of a boiling water sublayer on pool fires. Boilover is a very complicated phenomenon, so far the fire behavior and the formation mechanisms of boilover have not been fully understood yet.

The objective of the work presented here is to improve our understanding for the physics of the boilover process, and to explore a new way for detecting the occurrence of boilover. In this paper, the fire behavior of the boilover process is observed. Local temperature histories of oil-water sublayers during the burning progress are measured. The characteristics of combustion noise to boilover process are analyzed in time and frequency domains.

2. EXPERIMENTAL METHODS

(1). Apparatus

The experimental set-up is given schematically in Fig.1. Oil tank models made using stainless steel. The asbestos powder is filled in the space between the tank model and its outer casing, so that to eliminate environment effect. The system to drain the remained oil-water away, which consists of a pipeline and the cut-off valve, is mounted under the bottom of the tank model.

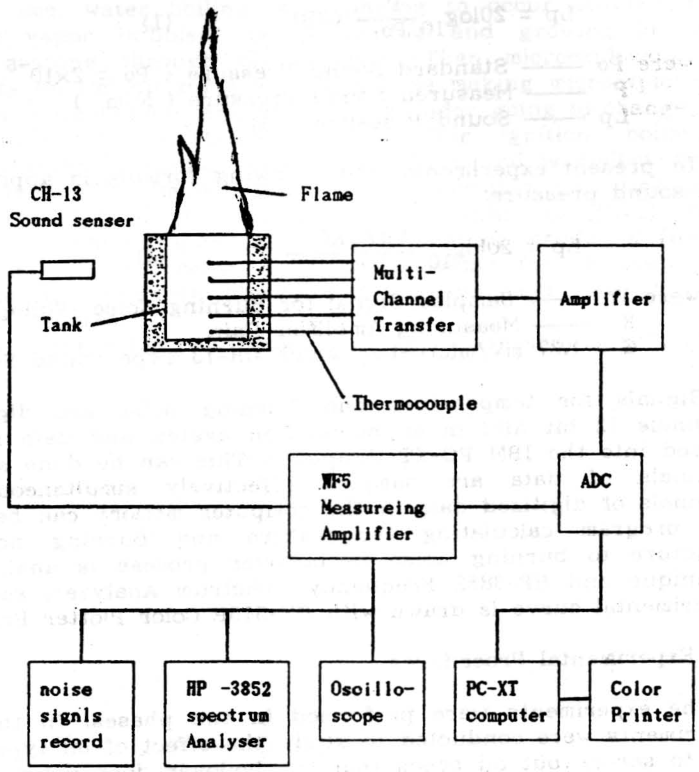


Fig.1. Scheme of Experimental Apparatus

(2). Measuring Technique

The SONY DC-1820 Video Camera and Nikon 404 Camera were used to visualize the flame behavior in boiliver process. Time averaged flame heights also determined by a still camera and a video camera records. The local temperature histories within oil-water sublayers during the progress of combustion are measured using nickel-chrome nickel-silicon thermocouples sheathed with a 0.5 mm diameter stainless steel tube.

The noise measuring system consists of a CH-13 type sound sensor and a model NF5 measuring amplifiers equipped with low and high pass filters set. The sound pressure, which to measure noise level, is defined by

$$Lp = 20\log_{10}\frac{P}{Po} \text{ (dB)} \qquad (1)$$

were Po —— Standard Sound Pressure ($Po = 2\times10^{-5}$ N/m^2)
P —— Measured Sound Pressure (N/m^2)
Lp —— Sound Pressure (dB)

In present experiments, the following formula is applied to calculate the sound pressure:

$$Lp = 20\log_{10}\frac{Vo/(KG)}{Po} \qquad (2)$$

were Vo —— Sampled Signal for Burning Noise (Voltage)
K —— Measuring Amplifier Gain
G = 1.37 mV/micro-bar which CH-13 Type Sound Sensor Sensitivity

Signals for temperature and burning noise are digitized by two channels 12 bit ADC in an acquisition system and data information are passed into the IBM PC-XT Computer. This can be done so that the two channels of data are sampled effectively simultaneously. The two channels of digitized data in the computer memory can be processed by the program calculating temperature and burning noise. Spectrum structure to burning noise in boilover process is analyzed with FFT technique and HP-3852 Frequency Spectrum Analyzer, separately. Then experimental curve is drawn with CE-515P Color Plotter Printer.

(3). Experimental Procedures

The experiments were performed in two phases. In the first phase, experiments were conducted to study the effect of oil types on boilover, and to screen out oil types that the boilover does not occur. A variety of single component and multi-component fuels in tank models of two sizes, i.e. inner diameters 60, 100 mm were tested.

In the second phase, it is given emphasis to study Fire behavior of boilover process. Three different oil tank models of inner diameters 60, 100 and 200 mm are tested. Daqing crude oil, gasoline, mixed oil with different proportion of machine oil and gasoline or kerosene as fuels were used.

3. EXPERIMENTAL RESULTS AND DISCUSSION

It is found from the experimental observations that boilover process can be divided into three stages: quasi-steady period, boilover premonition period and boilover period. Photographs of flame are shown in Fig.2((a).(b).(c)) typical fire behavior at the three burning stages for Daqing crude oil. Photograph (a), taken 5.0min after ignition, the flame is to appear a quasi-steady state. Photograph (b), taken 19.0min after ignition, that is typical flame structure at boilover premonition period. At this time, water boiling is beginning to occur at oil-water interface; water vapor bubbles are generating and growing at the interface and escaping through oil sublayer. Then microexplosion to water-oil droplets on the oil surface occurred, as making microexplosion sound. The flame is unstable. Flame behavior is under going to change at this stage. Photograph (c), taken 19.2min after ignition, boilover occurred. Flame height is sharply increased. Burning oil is spilled over the around of tank. The flame structures for gasoline pool fire are given in Fig.2((e).(f).(g)). To compare photographs (e).(f).(g) for gasoline flames with photographs (a).(b).(c) for Daqing crude oil fires, it is evident that the difference to flame behavior for the two oil types. The flame is relatively steady for gasoline pool fire at the whole combustion process.

Average flame heights for two different oil types are shown in Fig.3.

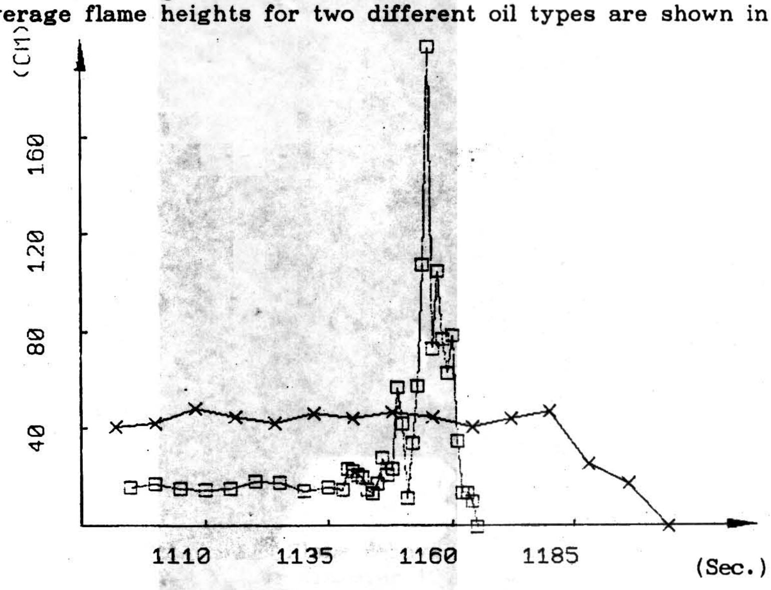
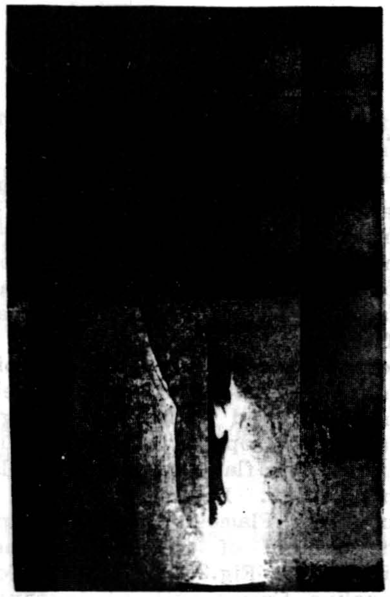
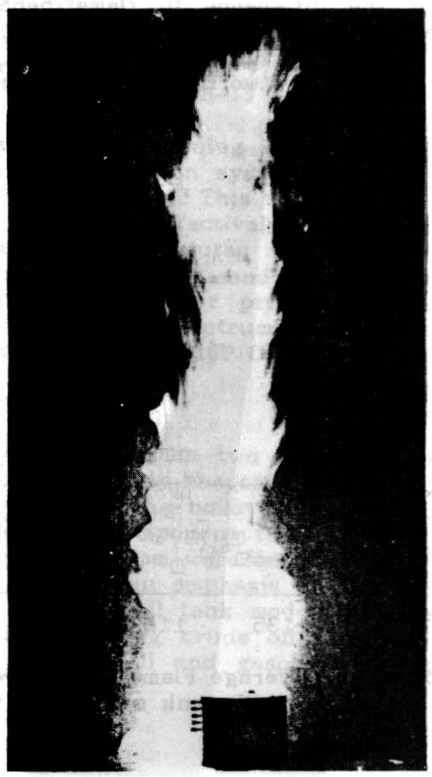


Fig.3. Variation of the Average Flame Heights With Burning Time
(□ Daqing crude oil x gasoline tank model with inner diameter 100mm)

(a)



(b)



(c)

(e)

(f)

(g)

Fig.2. Typical Flame Behavior in Boilover Process
(inner diameter 100mm tank model)
(a).(b).(c).for Daqing crude oil
(a). Quasi-steady period
(b). Boilover premonition period
(c). Boilover period
(e).(f).(g).for gasoline

For Daqing crude oil fires, the average flame heights are almost constant at quasi-steady period. The significant variation of flame heights occurs at boilover premonition period, due to the effect of water boiling on burning. They sharply increase when boilover occurs. However, there is no obvious chang for gasoline flame heights at the whole burning process.

Fig.4. and Fig.5 shown the temperature variations as a function of time at different position inside fuel-water sublayers with each 200 ml Daqing crude oil and gasoline. Curve No.3 expressed temperature history at oil-water interface. It is found in Fig.4 that combustion state is in the boilover premonition period, when water temperature at the interface arrived 100 ^{o}C. Then the temperature is continued to rise, and to get the super-heat state. The oil-water interface temperature at boilover period sharply rised, and get to a maximum temperature. Then the temperature go down very quickly.

We have found in experiments that burning noise, which occurs in pool fires with water sublayer, can be distinguished with microexplosion noise and boilover noise. The former is due to the small scale of water bubbles formation at quasi-steady and premonition periods. The latter occurs at boilover period, which is related to the process of growing of large scale bubbles at oil-water interface, and to vapor pressure sharply rise at the interface. The variations of noise level with burning time for Daqing crude oil and gasoline given in Fig.6, 7, separately.

Fig.6 indicates that burning noise level is quite different at three burning stages. for Daqing crude oil. The sound pressure is significantly increased at boilover premonition period. It is to reach maximum value when boilover occurs.

Fig.7 shown the magnitude of burning noise at the whole process of combustion for gasoline pool fires is very small. It may be nearly neglected. There are little change near the and of burning process.

The typical noise spectrum structure at three burning stages for Daqing crude oil given in Fig.8. Fig.(a) is a typical noise frequency spectrum at quasi-steady period. A typical noise spectrum at boilover premonition period is shown in Fig.8(b). It be noted that burning noise is distributed in a broad frequency domain. Because microexplosion noise is dominant aspect at this burning stage, the maximum value of noise level is occurred in higher frequency region. However, we can see from Fig.8(c) that noise spectrum is to shift toward lower frequency region at boilover period, because boilover noise is main aspect at the burning stage.

4. CONCLUSIONS

The fire behavior of boilover process for oil pool fires were studied by the means of flame structure visualization, measuring local temperature histories within oil-water-sublayers, and burning noise analysis.

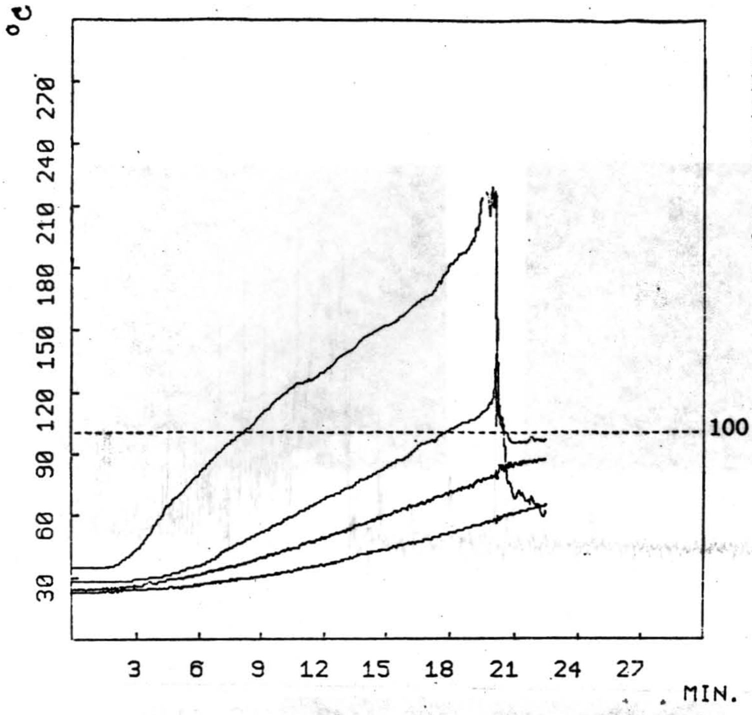


Fig.4. Temperature Histories in Boilover Process
1. in Oil sublayer
2. Oil-water Interface
3. 4. in Water Sublayer
(Daqing crude oil)

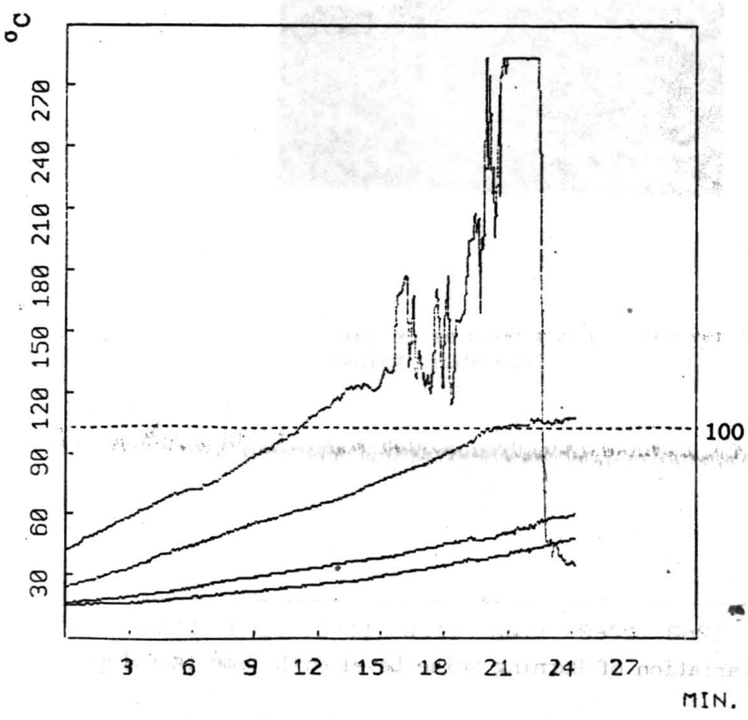


Fig.5. Temperature Histories in Burning Process (gasoline)

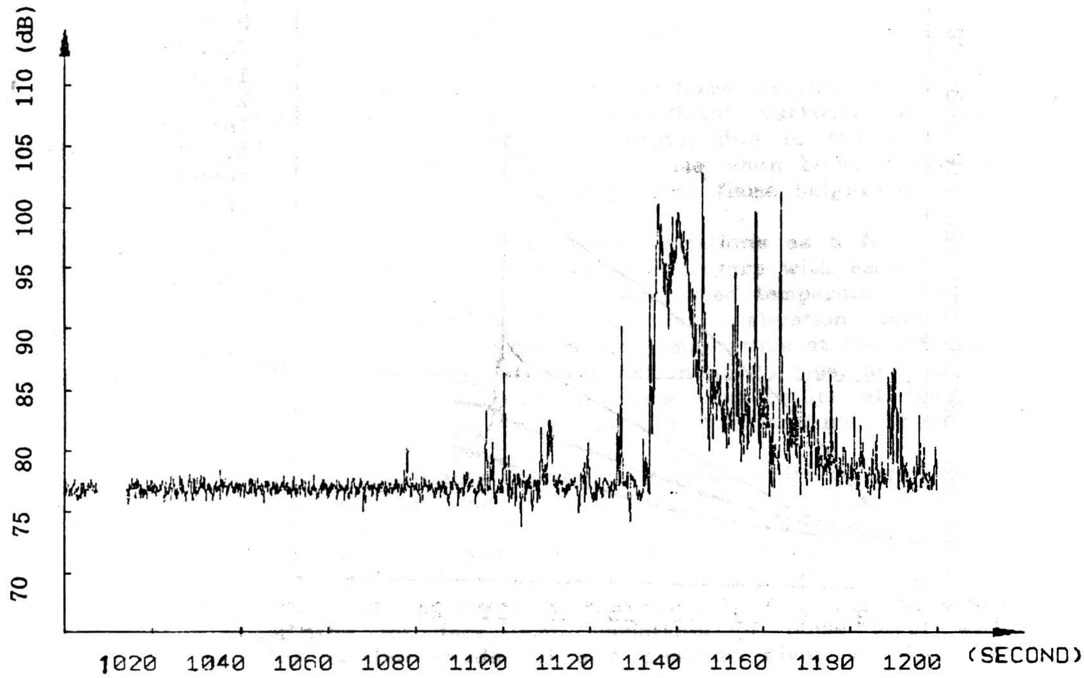


Fig.6. Variation of Burning Noise Level with Time (Daqing crude oil)

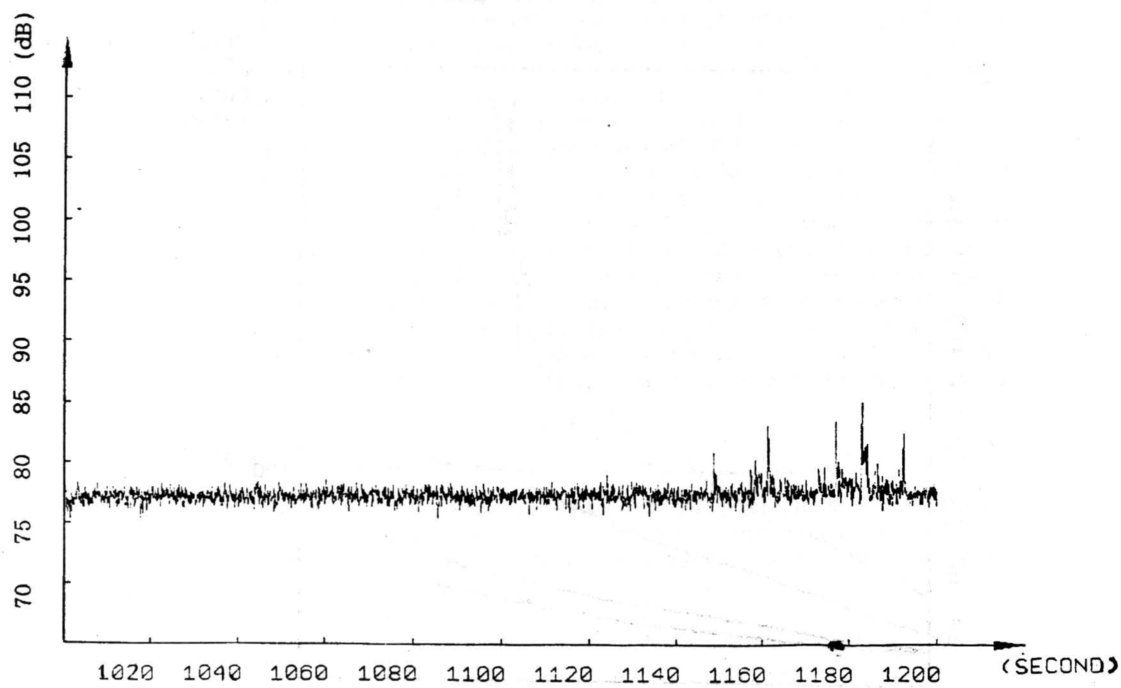
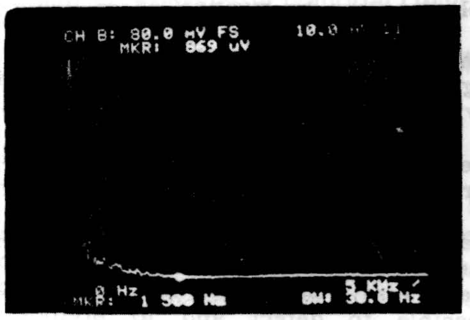
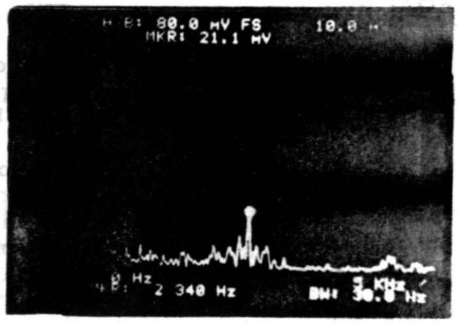


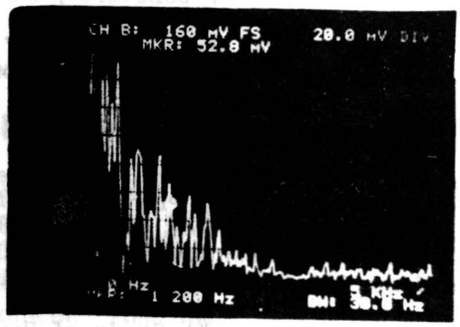
Fig.7. Variation of Burning Noise Level with Time (gasoline)



(a)



(b)



(c)

Fig.8. Typical Burning Noise Spectrum in Boilover Process (Daqing crude oil)

From above results, some conclusions can be summarized as follows:

(1). The boilover process of the pool fires for most oil types may be divided into three burning stages: quasi-steady, boilover premonition and boilover periods. Fire behavior at three stages for given oil type is different.
(2). The burning noise in boilover process for most oil types ,specially heavy oil types, will occur. Burning noise can be distinguished with microexplosion noise and boilover noise.
(3). It is evident that premonition for most oil types exits in boilover process. The microexplosion noise is one of characteristics of boilover premonition. According to the noise characteristics of boilover premonition period, that is possible to detect and to predict the occurrence of boilover.
(4). The burning noise level at three burning stages for given oil type is quite different. In addition, it is also closely related to thermal structure within oil-water sublayers in boilover process.

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