KAERI/TR-1984/2001

증기분사기의 형상이 직접접촉응축 성능에 미치는 영향

Effect on the Performance of a Shape Factor of Sparger During Direct Contact Condensation of Steam

2001. 12

한국원자력연구소

제 출 문

한국원자력연구소장 귀하

본 보고서를 “원전 안전계통 실증실험” 과제에서 수행된 증기분사기를 사용한 증기방출시 하중특성에 대한 실험 연구의 기술보고서로 제출합니다.

2001. 12. 20.

저 자 : 조 석 (열수력안전연구팀)

윤 영 중 (열수력안전연구팀)

정 흥 준 (열수력안전연구팀)

천 세 영 (열수력안전연구팀)

백 원 필 (열수력안전연구팀)

요 약 문

I. 제 목

증기분사기의 형상이 직접접촉응축 성능에 미치는 영향

II. 연구개발의 목적 및 필요성

차세대원자로(KNGR)에는 자체의 안전성을 증대하기 위하여 안전감압계통과 같은 새로운 안전설계개념들이 도입될 예정이다. 안전감압계통은 가압기 안전밸브의 작동시 고압의 증기를 감압배관과 증기분사기(sparger)를 통하여 containment 내부의 재장전수 저장탱크(IRWST)로 분사한다. 증기분사기의 역활은 고압의 증기를 응축수내에서 효율적으로 응축시키고, 증기의 분사시 물-증기의 직접접촉응축(Direct Contact Condensation)에 의해 발생되는 압력하중을 감쇄하는 것이다. 따라서 다공의 증기분사기에 의해 발생되는 직접접촉응축 현상에 대한 이해는 원자로의 안전과 운전을 위해 필수적인 것이다. 지금까지의 직접접촉응축에 대한 연구는 주로 단공의 노즐을 통한 응축 열전달의 측면에서 이루어졌고, 다공의 증기분사기에 의한 직접접촉응축과 압력하중특성에 대한 연구는 미미한 실정이다. 본 연구의 목적은 증기분사기의 형상에 따른 증기분사성능과 압력하중특성 파악이다.

III. 연구개발의 내용 및 범위

본 연구에서는 1인치 I-형 증기분사기의 분사구배열(Hole pattern)과 P/D (Pitch to diameter ratio)의 변화에 따른 증기분사기의 성능을 비교하기 위하여 분사구배열과 P/D율(2, 3, 4, 5)을 변화하여 총 8가지 종류의 증기분사기를 사용하여 실험을 수행하였다. 과냉각수의 온도는 30 ~ 95℃, 증기유량은 70 ~ 215kg/m^2-s의 응축진동영역(Condensation oscillation regime)으로 제한하였다. 본 보고서에서는 증기방출시 응축수 저장탱크 벽면에서의 압력거동을 하중의 크기와 주 진동수의 측면에서 논하였고, 증기발생기의 종류에 따른 수조내 열혼합 특성을 비교하였다.

IV. 연구개발결과

압력하중에 영향을 주는 주된 변수는 응축수의 온도, 증기유량, 증기분사기의 형상등이 있다. 증기분사기의 P/D가 증가할수록 하중의 크기는 증가했으며, 분사구배열에 따라서 수조내 열혼합 성능에 차이를 관찰하였다. 주 진동주파수는 99

~ 759Hz 사이에서 변화하였으며, 응축수의 과냉각도와 P/D가 증가할수록 증가하는 경향을 보였다. 본 연구에서 얻어진 실험자료를 단공의 노즐에 의한 자료와 비교하였고, 이를 바탕으로 증기분사기의 분사구간 간섭효과(Interaction effect)를 고려한 주파수 상관관계식을 제안하였다.

V. 연구개발결과의 활용계획

본 연구는 여러종류의 증기분사기를 통한 증기분사시(Steam discharging period) 응축진동영역에서 발생하는 동압특성을 하중크기와 주 진동수의 관점에서 비교하였다. 이를 통해 증기방출구간의 간섭효과를 규명하였고, 증기분사기의 설계시 유용한 자료를 생산하였다. 본 팀에서는 현재 차세대원자로 원형 증기분사기를 사용해 공기방출시(Air clearing period) 동압특성을 파악하기 위한 Unit Cell Test를 수행중에 있다. 본 연구를 통해 얻어진 결과는 Unit Cell Test의 결과와 함께 증기분사기의 설계 및 성능검증용 실험자료로서 활용될 것이다.

SUMMARY

I. Title

Effect on the performance of a shape factor of sparger during direct contact condensation of steam

II. Objectives and Background

KNGR adopts several advanced safety design features to enhance its safety such as SDVS (Safety Depressurization and Vent Sytem) and IRWST. Sparger will be installed in the IRWST. The roles of sparger is to discharge of high pressure steam from RCS during postulated accident and to increase quenching efficiency of steam and alleviate probable pressure surge. Therefore, understanding DCC (Direct Contact Condensation) phenomena of multiple-hole sparger is important to ensure structural integrity of the reactor system and their safe operation. Previous works on the DCC, however, mainly focused on the heat transfer coefficient evaluation by using single-hole nozzle. Objectives of the study is to investigate the performance of sparger during steam discharging period and the characteristics of dynamic pressure load with the variation of geometric configuration of sparger.

III. Contents and Scope

An experimental study has been carried out to investigate the performance of eight different I-type spargers in view of pressure oscillation and thermal mixing in a pool. Its pitch-to-hole diameter, *P/D*, varies from 2 to 5. The test conditions are restricted to the condensation oscillation regime, pool water temperature of 30 ~ 95℃ and steam mass flux of 70 ~ 215kg/m^2-s. In this study, the characteristics of pressure loads at the quench tank wall are discussed in view of pressure amplitude and oscillation frequency and the thermal mixing performance of each sparger in a pool is compared.

IV. Results

The major parameters affecting the dynamic pressure are the pool water

temperature, the steam mass flux, and the geometric configuration of sparger. The amplitude of pressure peak is increased with the P/D. The thermal mixing performance is varied with the hole pattern of sprager. The dominant frequencies lie between 99 and 759Hz and increase with the degree of pool subcooling and P/D. A new frequency correlation is proposed in terms of P/D and other thermal hydraulic dimensionless parameters.

V. Application

The present study presents the characteristics of dynamic pressure in view of amplitude and frequency in condensation oscillation regime during steam discharging period. The interaction effects are identified. Useful data for sparger design are also produced. The Unit Cell Test is being performed by thermal-hydraulic safety research team in KAERI to investigate the air clearing performance. The results of the present study and those of the Unit Cell Test will be used as a reference data of basic design and performance verification of sparger.

CONTENTS

목　　차

표 목차

그림 목차

1. Introduction

Direct contact condensation (DCC) phenomena is encountered in several components of a nuclear power plant during some transient or accident conditions. For example, in the loss of coolant accident (LOCA) of a pressurized water reactor, steam may come into direct contact with cold water at several locations such as a cold leg, a downcomer, a hot leg, and upper and lower plena. DCC phenomena are also expected to occur in the in-containment refueling water storage tank (IRWST) of the Korea Next Generation Reactor (KNGR), when the reactor depressurization system valves or the pressurizer safety valves are open to discharge steam into the quench tank through a steam discharge device (sparger). Understanding of the DCC phenomena such as characteristics of the pressure pulse is very important for an optimal design of the sparger to ensure structural integrity of the reactor system and their safe operation.

Although a large number of studies on the DCC phenomena have been investigated theoretically and/or experimentally, the phenomena are not yet well understood. The previous works were mainly focused on the heat transfer coefficient and dimensionless jet length, to correlate them with the steam mass flux and pool water temperature. Moreover, in all of these previous works employed a single-hole nozzle for the investigation of the basic mechanism of the DCC phenomena. Arinobu (1980) experimentally investigated the dynamic phenomena of chugging and condensation oscillation, which takes place in relatively low steam mass flux conditions, and insisted that the dominant frequency of the pressure pulse decreases with increasing pool temperature and nozzle diameter, but increases with increasing steam mass flux. Based on the experimental observations, he proposed the frequency relation as in Eq. (1).

$$f = 0.8V/D[(C_p \Delta T)/h_{fg}]^{1.4} \qquad (1)$$

where f is the dominant frequency in Hz and V means the steam velocity at the exit of the vent pipe in m/s. Fukuda (1982) also asserted that the dominant frequency is proportional to the degree of pool water subcooling and inversely proportional to the nozzle size. In accordance with this speculation, he suggested the simple frequency relation as follows:

$$f = 60.0\ \Delta T \ /\ D \tag{2}$$

where ΔT is the subcooling temperature of water in °C. Cho et al. (1999) insisted that in some operating conditions, condensation takes place in a very unstable manner such that the steam jet begins to oscillate with relatively large pressure pulses. They emphasized that the transition between unstable and stable regimes depends on the nozzle diameter, the steam mass flux and the pool water temperature.

The previous works mentioned above simply presented the characteristics of a single-hole nozzle (or vent tube). Sparger, however, is a multi-hole device. It is expected that the characteristics of pressure pulse of a multi-hole sparger is different from those of the single-hole nozzle due to the interaction of the discharging steam jets. Therefore, the condensation characteristics of a multi-hole sparger must be understood. In order to expand the single-hole relations to a multi-hole sparger, the interaction of the discharging steam with its neighboring steam jets and the sparger shape factor, which can be represented by the pitch-to-diameter ratio, P/D, and the hole distribution pattern must be considered.

The objectives of the present study is to provide the basic understanding of the condensation characteristics of the multi-hole sparger. One of the objectives of the present study is to investigate the dynamics of pressure oscillation in terms of amplitude and dominant frequency when steam is fed through various kinds of multi-hole I-type spargers in subcooled water. The other objectives are not only to investigate the performance of each sparger tested here with respect to the pressure behavior and thermal mixing effect in a pool, but also to compare multi-hole sparger data with those of a single-hole nozzle to clarify the multi-hole effect. These data will contribute to the construction of a basic database on the performance of several types of spargers.

2. Experimental Method

The experimental facility consists of a steam generator, a quenching tank, steam supply lines, valves and instruments. A schematic diagram of the sparger and the locations of the instruments in the quench tank is shown in Fig. 1. The steam generator with electric heaters of 300kW produced steam continuously with dryness higher than 99%. The maximum operating pressure was 1.03MPa and the maximum steam flow rate was 0.12kg/s. Subcooled water is contained in the quenching tank equipped with two plexi-glass windows for visual observation and video camera imaging. The quenching tank is a horizontal cylindrical tank open to the atmosphere, in its diameter and length of 1m and 1.5m, respectively. The nominal size of the steam supply line and spargers is 1 inch, schedule 40, ANSI standard stainless pipe. The steam supply line is heated by trace heaters and insulated in order to maintain the supplied steam saturated with about 99% dryness during the test. A vortex type steam flow meter, a manual flow control valve, a drain valve, an isolation valve, a pressure transmitter, and a thermocouple are installed in the steam supply line. Nine thermocouples are also installed inside the quenching tank to measure the pool temperature, and a piezoelectric type pressure transducer is installed on the tank wall, 75cm away from the axis of the sparger. A data acquisition system, which consists of an IBM-compatible computer and a 12-bit A/D converter, processes all signals. The sampling rate is 4,096Hz. All the instruments were calibrated before testing.

Eight different kinds of spargers with a steam-discharging hole diameter of 5mm were tested for various combinations of the steam mass flux and the pool temperature. The manual flow control valve installed in the steam supply line controls the steam mass flux. The submergence of the centerline of the vertically distributed injection holes of the sparger is maintained at about

36cm below the free surface of the pool water during the test.

When the steam generator isolation valves are open, a small amount of water and air inside the steam supply line is discharged first. After clearing out the water and air in the line, steam from the steam generator is continuously discharged into the pool. At the initial stage of steam discharge, it was observed that some dissolved gas in the pool changes into a lot of tiny gas bubbles, but they are disappeared when the pool temperature is increased higher than 30°C. As the steam is continuously discharged into the pool, the mean temperature of subcooled water in the quench tank begins to increase until it reaches the pre-setting value. Test conditions and technical specifications of spargers can be seen in Table 1.

3. Experimental Results and Discussion

DCC phenomena can be classified mainly in terms of steam mass flux and water subcooling in the condensation flow regime map (Aya et al., 1983; Sonin, 1984). In the case of a steam mass flux lower than 55 ~ 65 kg/m^2-s, the chugging phenomenon may occur (Chan, 1978). In some cases of a steam mass flux higher than 70 kg/m^2-s, periodic pressure variation induced by oscillatory movement of the steam-water interface is observed in the pool. This phenomenon is called a condensation oscillation. Typical images of steam jets taken in the case of Sp6 at G = 106 kg/m^2-s are shown in Fig. 2. As the pool temperature increases, the length and diameter of the steam jets become large and the jets are then combined with neighboring ones.

The typical pressure signals observed in the case of Sp8 with a mass flux of 141 kg/m^2-s are seen in Fig. 3. As can be seen in Fig. 3, the amplitude of the pressure pulse at the low temperature condition is very small, but its frequency is relatively high. As the pool temperature increases, the amplitude reaches its peak and then it decreases with increasing pool temperature. It is noticeable that the frequency of positive peak pressure decreases as the pool temperature increases. The pressure signals shown in Fig. 3 indicate that the pool temperature has a strong influence on the amplitude and frequency of pressure oscillation.

3.1 Amplitude of the pressure pulse

In this section, the influence of the steam mass flux and pool temperature on the pressure amplitude will be discussed. Figures 4 and 5 show the variation of root-mean-square pressure amplitude with the steam mass flux and the pool temperature for the eight different spargers. According to the previous work (Cho et al., 1999), the amplitude of the pressure pulse is quite closely related to the condensation modes. In other words, the pressure pulses in the condensation oscillation mode show much larger amplitude than those in the stable condensation mode, when the pool temperature is maintained at a constant level. The difference in the pressure amplitude between these two condensation modes becomes smaller as the pool temperature increases. Due to this fact, the test conditions in the present study are limited to the condensation oscillation mode.

In the case of the single nozzle experiments (Cumo et al., 1978; Damasio et al., 1985; and Tin et al., 1982), it was observed that, in general, the amplitude of the pressure pulse initially tends to increase with increasing the pool temperature. The amplitude reaches a peak value at a pool temperature of around 60 ~ 80°C, which varies depending on the discharging nozzle size and the steam mass flux. Sonin (1984) suggested the peak may occur at a finite subcooling due to the facts that the peak amplitude requires a low subcooling enough to have a large bubble and a high subcooling enough to have a short collapse time. The pressure then decreases steeply before the water reaches the saturation temperature. This trend could also be observed in the present study and shown in Figs. 4 and 5.

In the present study, however, the pressure peaks can be observed at a relatively lower mean temperature than those of previous works, especially in the case of low steam mass flux conditions with Sp1 and Sp2. This phenomenon can be explained by considering both the interaction of neighboring steam jets and the difference between the water temperature in the vicinity of steam-water interface and the mean temperature of pool water. The *P/D* ratio of Sp1 and Sp2 is 2, which is very small. Therefore the steam jets tend to become more interactive with neighboring jets than those of the other spargers. During the interacting process between the neighboring jets, steam jets are readily combined with other jets to build extremely unstable bubbles around the sparger, which look just like a doughnut. As a result of the interaction, the kinetic energy of steam jet, - i.e. a driving force of thermal mixing in a pool, is decreased rapidly. In consequence, the temperature of water in the vicinity of these steam bubble-water interface increases more rapidly than the mean temperature of the pool water due to the weak convective force around the steam jets. The important factor affecting the dynamics of condensation is not the mean temperature of subcooled water, but the local temperature around the steam-water interface.

Considering the descriptions mentioned above, it could be quite well understood the reason why the peaks occur at a relatively low mean temperature of pool water with Sp1 and Sp2. The dynamics of the DCC of steam discharging through a multi-hole sparger are partially affected by the interaction of neighboring steam jets. However, the interaction is also closely related to the configuration of the sparger, such as the *P/D* ratio. As the *P/D* ratio decreases, the effect of the interaction becomes stronger. Therefore, in order to characterize the dynamics of the DCC through a multi-hole sparger, the effect of the hole configurations must be considered.

It can be seen from Figs. 4 and 5 that the peaks of pressure at the specified steam mass flux are located in the range of pool temperature about 45 ~ 85°C, and the temperature with the peak pressures increases with the increment of the steam mass flux. It is also noted that the peak amplitudes increase with the *P/D* ratio of the sparger. However, the amplitude of staggered-type spargers have nearly the same value as that of parallel-type spargers. With the above-mentioned observations in mind, it can be said that the hole distribution pattern is less important than *P/D*.

Figure 6 shows the difference between the mean temperature of pool water and the local temperature, T_3, measured in the bottom of the tank (Refer to Fig. 1), at a steam mass flux of 71kg/m^2-s. The mean temperature is obtained with the three different thermocouples located in the quench tank such as thermocouples-7, 8, and 10. Therefore, the temperature difference serves as a potential indicator of the thermal mixing performance of each sparger. The larger the temperature difference is, the poorer the efficiency of the thermal mixing is.

As can be seen in Fig. 6, the thermal mixing performance is strongly dependent on the configuration of the sparger such as the *P/D* ratio and hole distribution pattern. The performances of the staggered-type spargers of Sp1, Sp3 and Sp5 are much poorer than those of the parallel-type spargers of Sp2, Sp4 and Sp6. Therefore, the effect of the hole distribution pattern should be considered as far as the thermal mixing performance is concerned in the design of a sparger. The *P/D* effect on the thermal mixing performance can be explained by considering the relation between the interaction of neighboring steam jets and the discharging velocity of steam which acts as a driving force of thermal mixing. In summary, the thermal mixing performance as well as the characteristics of the pressure pulse, such as amplitude and frequency, need to be considered for the proper design and/or selection of the sparger and quench tank.

3.2 Frequency of pressure oscillation

As mentioned above, direct contact condensation events generate pressure loads on the structure. In the condensation oscillation mode, especially, pressure fluctuation is characterized by dominant frequency. In the present study, pressure oscillations in the water pool are measured at low mass fluxes in the range between G = 70 and 215 kg/m^2-s which correspond to an unstable condensation mode. The location of the pressure sensor, whose resonant frequency is higher than 60 kHz, is shown in Fig. 1. The frequency of the pressure oscillation is analyzed with a fast Fourier transformation (FFT) technique (Bendat and Piersol, 1991). A typical pressure signal in the time domain is shown in Fig. 2.

Simpson et al. (1982) investigated the basic mechanism of steam condensation at a relatively low mass flux, and observed that the characteristics of unstable jets are quite different from those of stable jets. In the correlation of the frequency data of an unstable jet, they suggested a relation as Eq. (3),

$$\mathrm{St} = k_1 \, (\mathrm{Ja})^{a_1} \, (\mathrm{Re})^{b_1} \tag{3}$$

where Ja is the Jacob number, which is the ratio of the specific energy absorption capability of the liquid to the energy density of the steam, Re is the Reynolds number based on the nozzle diameter, and St is the density weighted Strouhal number. The constants in Eq. (3) are such that k_1 = 0.011, a_1 = 0.72, and b_1 = 0.25. Damasio et al. (1985) proposed an improved correlation of Eq. (4), which includes the Weber number to take into account the surface tension effect.

$$\mathrm{St} = k_2 \, (\mathrm{Ja})^{a_2} \, (\mathrm{Re})^{b_2} \, (\mathrm{We})^{c_2} \tag{4}$$

where the constants are such that k_2 = 0.001196, a_2 = 1.0849, b_2 = 0.9389, c_2 = −0.7670.

In Figs. 7 and 8, the variation of the dominant frequencies is shown with the degree of pool water subcooling. It is evident that the dominant frequency is nearly proportional to the subcooling of pool water. As discussed in the previous section, the pressure variation is closely related to the bubble dynamics such as the size and movement of individual bubbles. At low pool temperatures, the discharged steam shows a tendency to break up into small bubbles whose condensation speed is relatively fast and their lifetime is quite short. On the other hand, as the pool temperature increases, the size and lifetime of these disintegrated bubbles become larger. Accordingly, the dominant frequency increases with increasing pool subcooling. The dominant frequency increases slightly with the steam mass flux as shown in Fig. 7. Moreover, as the *P/D* ratio increases, the dominant frequency also increases as can be seen in Fig. 8. This is due to the fact that as the *P/D* ratio decreases, a discharging steam jet can readily combine with neighboring ones. As a result of this combination, the steam bubble becomes larger than that of a single jet. For this relatively large steam bubble, the period of condensation becomes longer than that for a small bubble. Therefore, the dominant frequency decreases slightly. Thus, it seems to be reasonable to summarize that the geometric configuration of the spargers such as the hole pattern and *P/D* ratio, as well as the dimensions of the sparger, are important factors affecting the frequency of pressure oscillation.

In Fig. 9, the experimental data of Sp8 are compared with other correlations. Damasio's correlation shows a good agreement with the present data. Since the *P/D* ratio of Sp8 is 5, the interaction between neighboring jets is much smaller than that of the others. As can be seen in Fig. 10, however, the difference between the present data and Damasio's correlation becomes larger as the *P/D* ratio decreases. This discrepancy comes from the effect of the interaction between the neighboring jets. Therefore, the shape factors such as the *P/D* ratio, hole pattern, and bore size of the spargers should be considered additionally to correlate the frequency data of various kinds of spargers.

In the present study, by considering the expected role of the major physical and geometric parameters governing the DCC phenomena, the following correlation can be suggested, which includes the shape factor of the sparger:

$$\mathrm{St} = k_3\,(\mathrm{Ja})^{a3}\,(\mathrm{Re})^{b3}\,(\mathrm{We})^{c3}\,(I_*)^{d3} \qquad (5)$$

The constants in Eq. (5) are such that k_3 = 0.00174, a_3 = 1.093, b_3 = 0.891, c_3 = −0.827, and d_3 = 0.298, and I_* is the shape factor of the sparger, which corresponds to the *P/D* ratio. It is noted that the effects of the other geometric factors are not included. A comparison of the Strouhal numbers between the experiments and correlation, Eq. (5) is shown in Fig. 11. The correlation predicts the experimental data fairly well within 20%. The mechanism regarding steam bubble oscillation in water, however, has to be studied more precisely.

It is noted that the dominant frequencies observed in this study are dependent on the dimension of the system such as the hole and the bore size of the spargers. Accordingly, it is strongly recommended that more systematic studies with various sizes of spargers must be carried out.

3.3 Uncertainty analysis

The uncertainty analysis has been performed in accordance with a 95 percent confidence level. According to the ASME performance test codes 19.1(1985), the uncertainty interval of the present results is given by the root-mean-square of a bias contribution and a precision contribution for the case of Sp8 at G = 144kg/m^2-s. The results show that the uncertainty intervals of the dominant frequency and the amplitude of the pressure signal are 1.1% (8.3Hz) and 0.8% (0.03kPa), respectively. The uncertainty interval of the steam mass flow rate is 3.57% of the measured value.

Table 1 Test conditions and technical specifications of the sparger.

Sparger Type	Sp1	Sp2	Sp3	Sp4	Sp5	Sp6	Sp7	Sp8
Pattern of hole (S : staggered, P : parallel)	S	P	S	P	S	P	S	P
Total number of holes (EA)	20		21		20		20	
P/D ratio	2		3		4		5	
Hole diameter (mm)	5							
Nominal size of sparger (mm)	1 inch, schedule 40, ANSI stainless pipe							
Total hole area /Flow area of sparger (%)	70.7		74.2		70.7		70.7	
Steam mass flux (kg/m^2-s)	70 ~ 215							
Pool temperature (℃)	30 ~ 95							

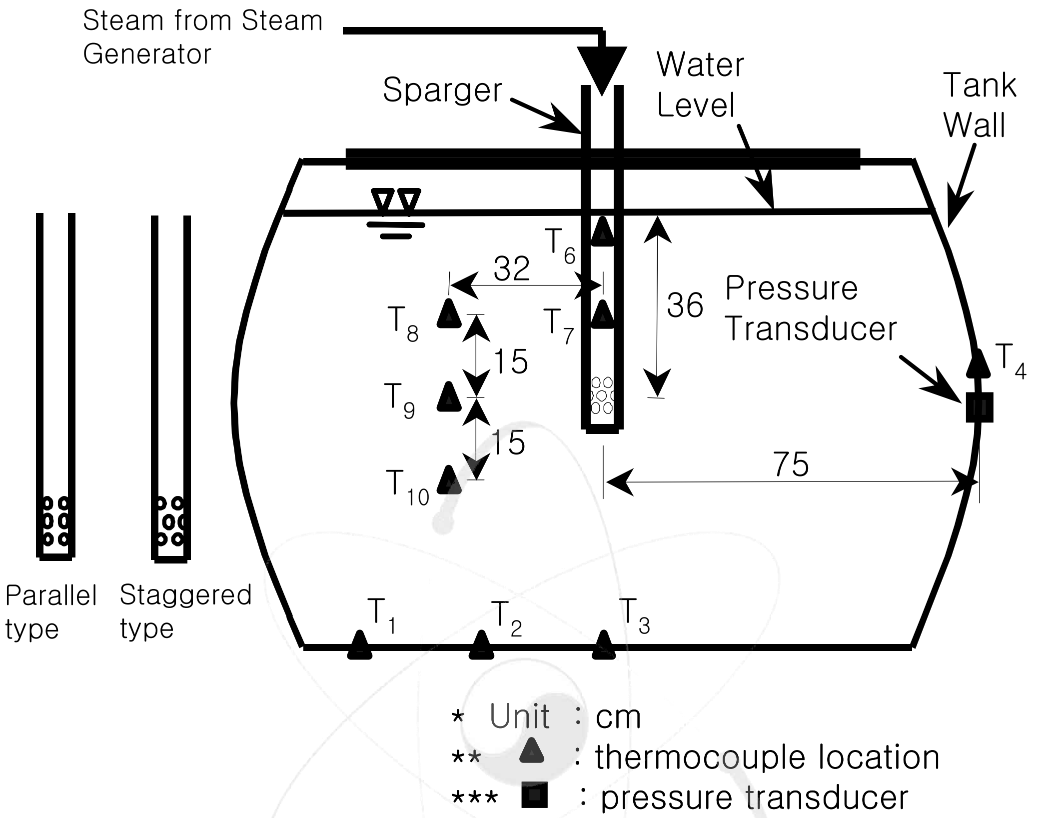
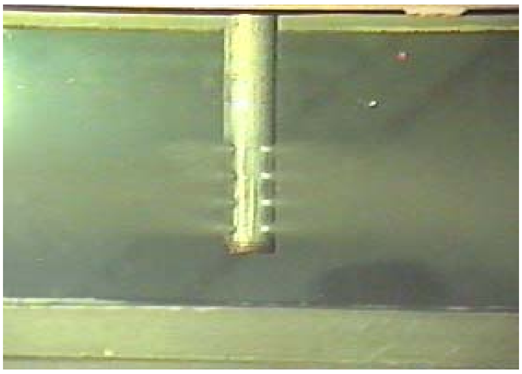
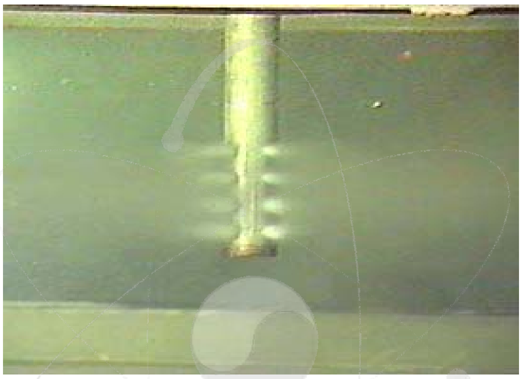


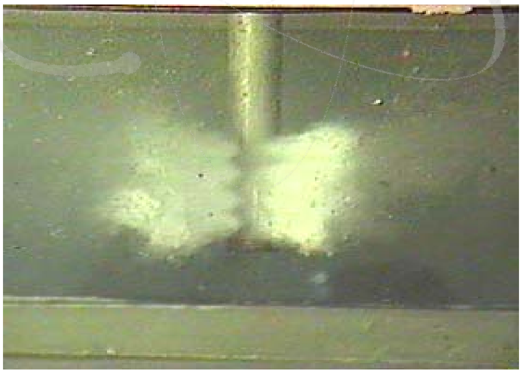
Fig. 1 Schematic diagram of the sparger and the locations of the instrumentation in the pool



(a) T_m = 35.2°C



(b) T_m = 65.1°C



(c) T_m = 94.9°C

Fig. 2 Typical shapes of the steam jet in the case of Sp6 at G = 106kg/m^2-s

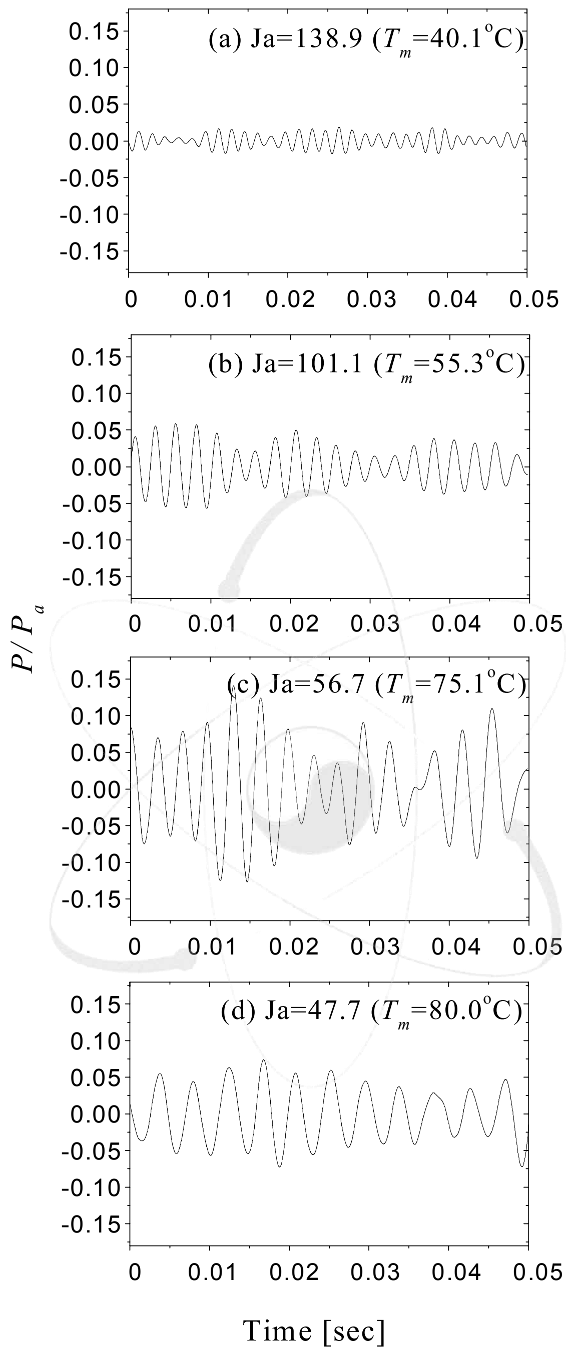


Fig. 3 Pressure signal measured at the wall with a variation of pool temperature in the case of Sp 8 at G =141 kg/m^2-s.

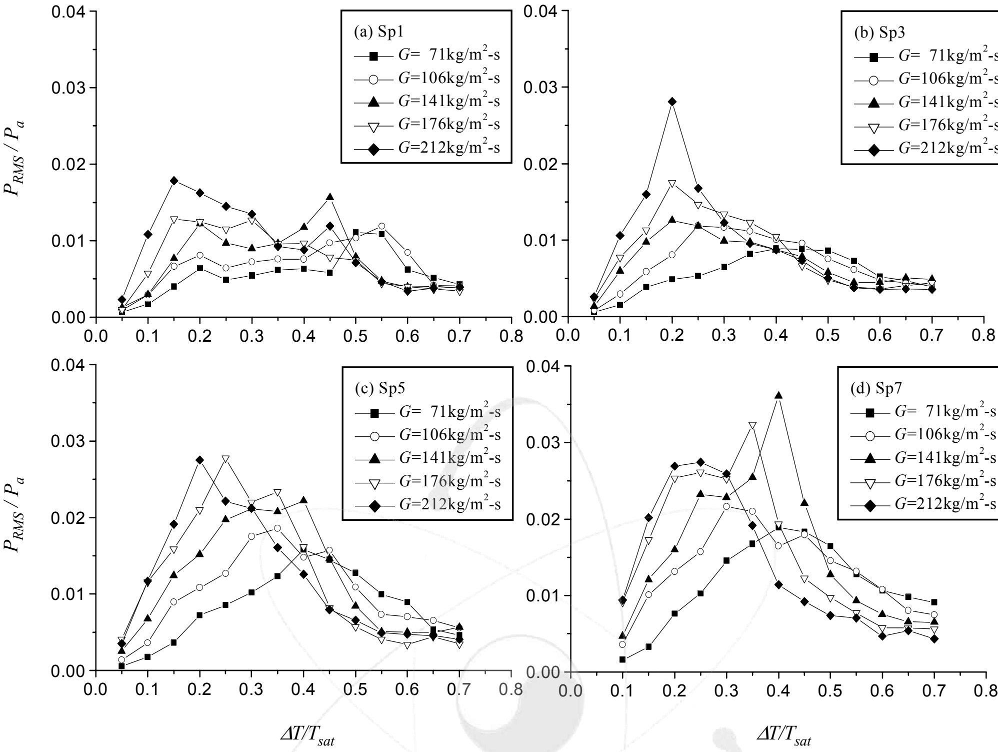


Fig. 4 Variation of pressure amplitude of staggered type spargers.

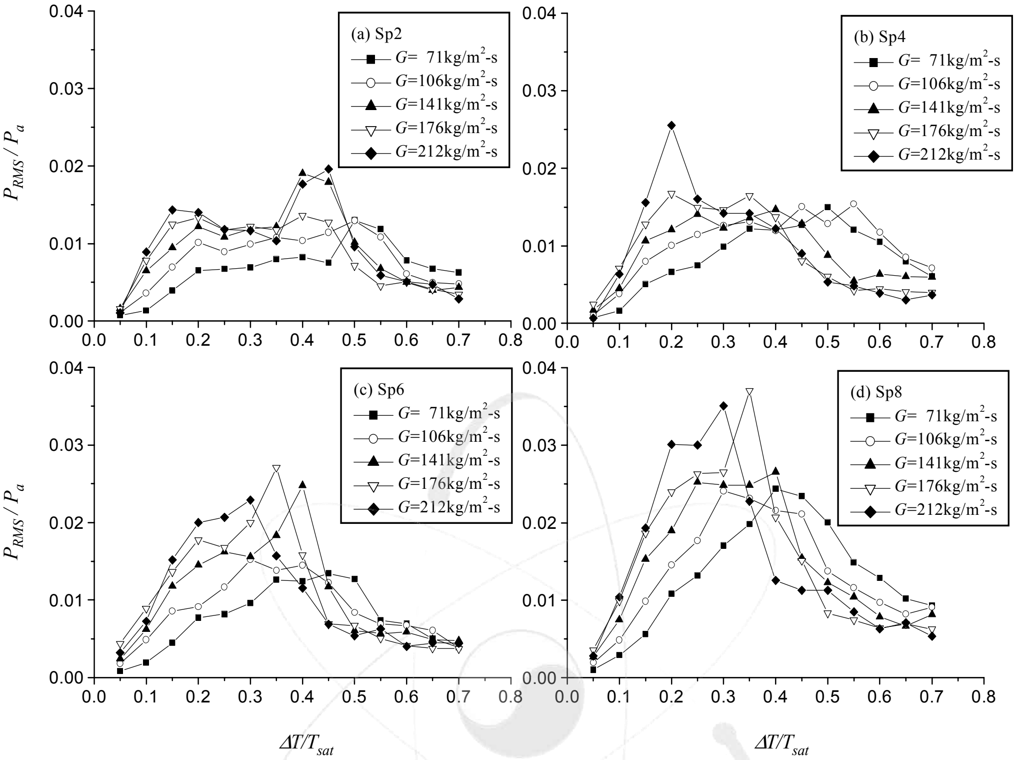


Fig. 5 Variation of pressure amplitude of parallel type spargers.

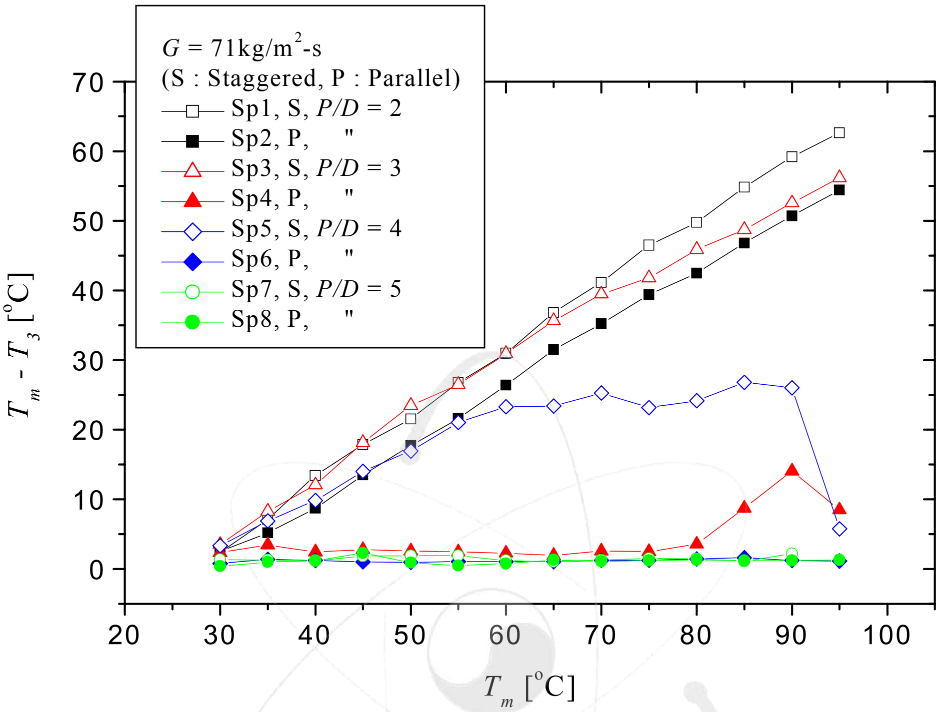


Fig. 6　Temperature difference between the mean value and T_3 with a variation of the sparger.

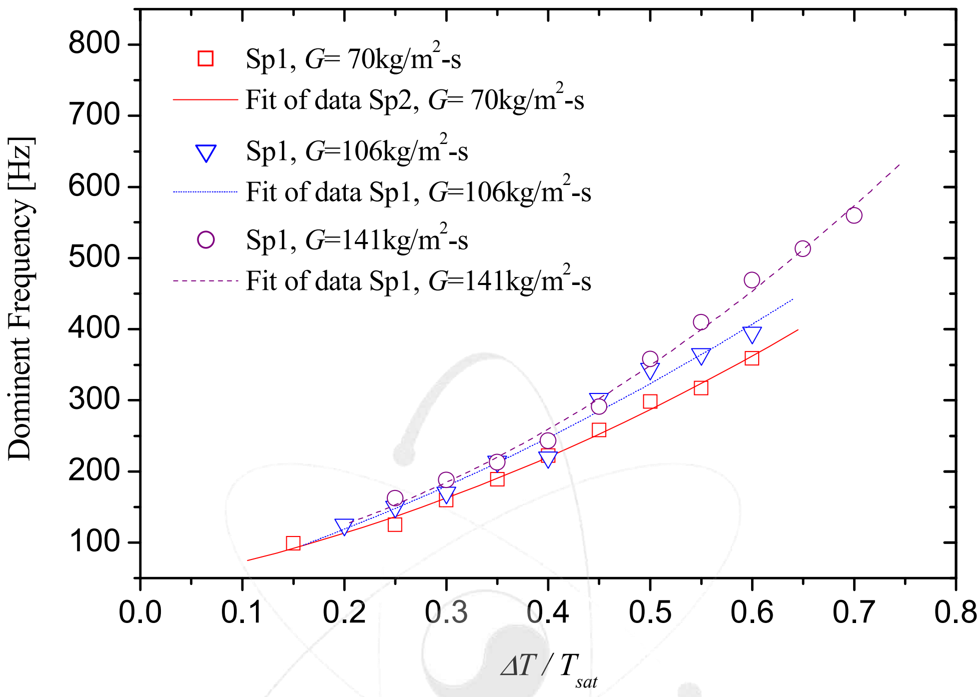


Fig. 7 Variation of the dominant frequency with the steam mass flux in the case of Sp1.

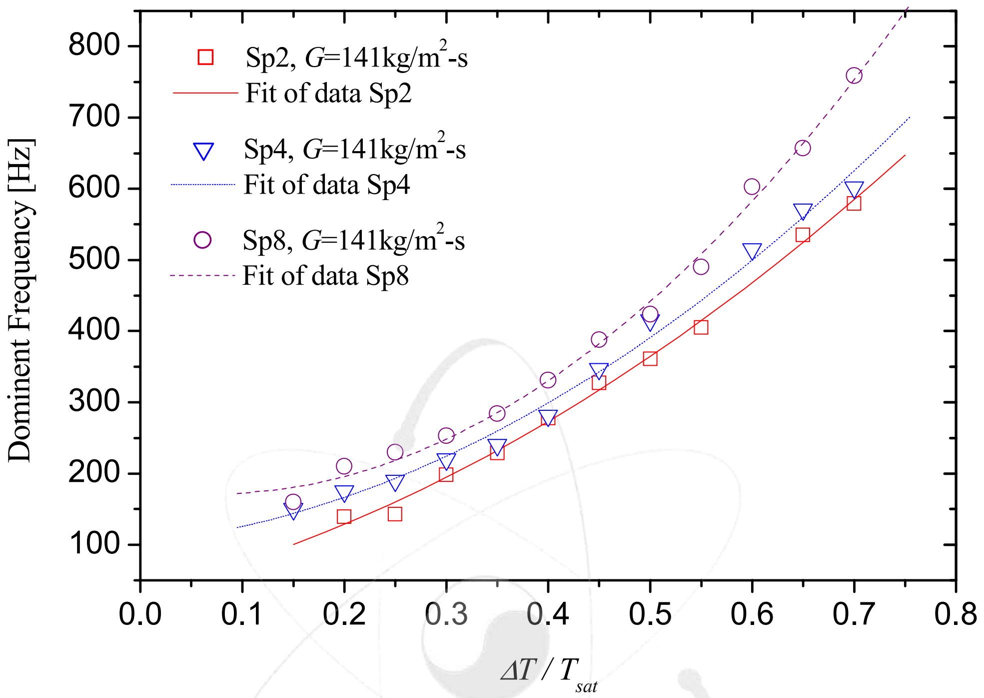


Fig. 8 Variation of the dominant frequency with the *P/D* ratio of the sparger.

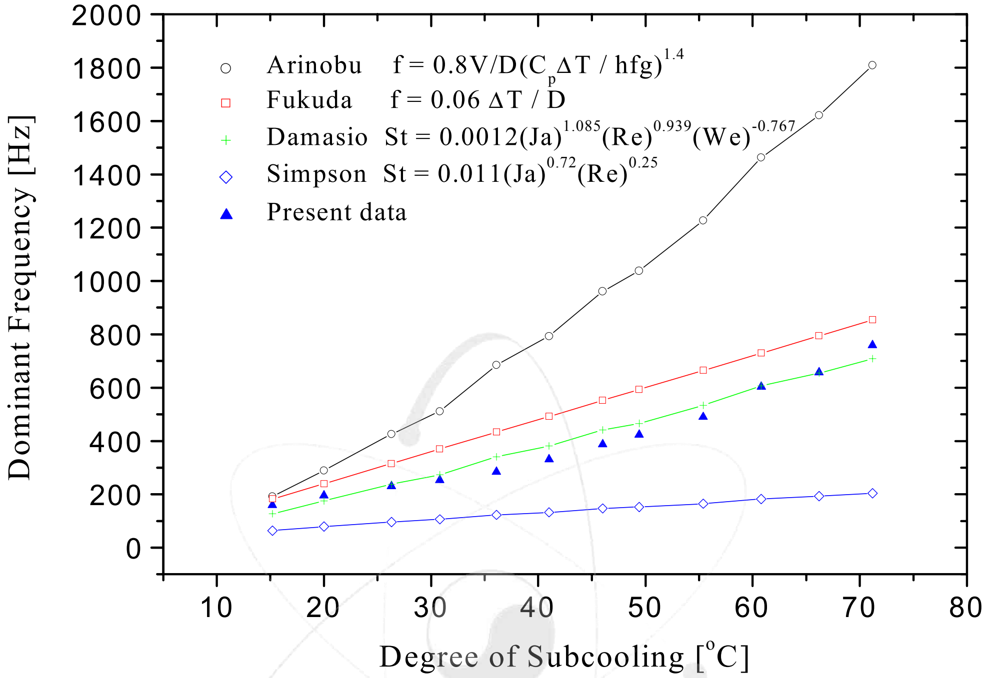
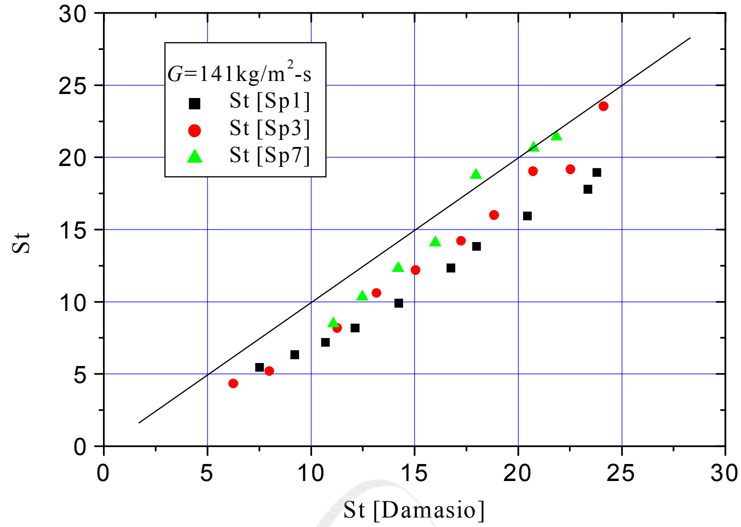
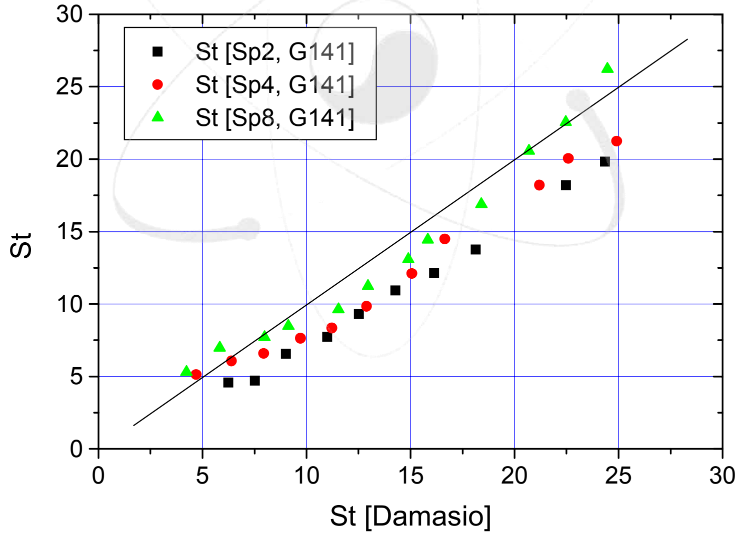


Fig. 9 Comparison of the dominant frequency with other correlations in the case of Sp8 at G = 141 kg/m^2-s.



(a) staggered type



(a) parallel type

Fig. 10 Comparison of Strouhal number with Damasio's correlation, Eq.(4).

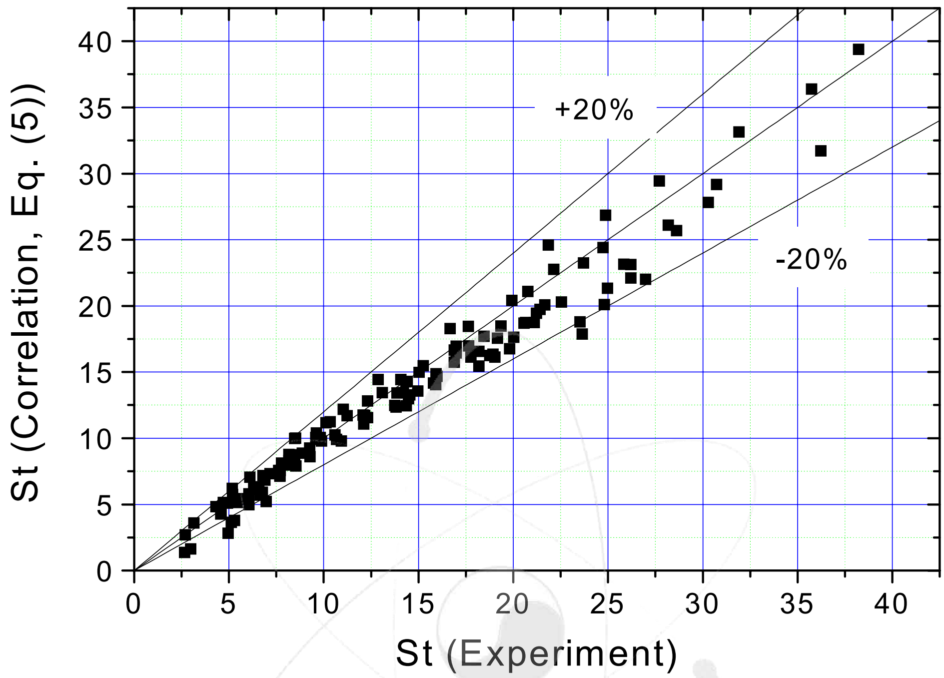


Fig.11 Comparison of Strouhal number between the experiment and correlation, Eq. (5).

4. Conclusions

Experimental investigations on the pressure loads induced by the direct contact condensation (DCC) of steam discharging into subcooled water have been performed for eight different spargers under various conditions of steam mass flux and pool water temperature. The major parameters affecting the trend of the pressure load are the configuration of the spargers such as the *P/D* ratio, the distribution pattern of the discharging holes, the steam mass flux and pool water temperature.

The major findings are summarized as follows:

(1) The amplitude of the pressure pulse shows a peak at a pool temperature of around 45 ~ 85°C depending on P/D and steam mass flux.

(2) The dominant frequency increases with the degree of pool subcooling and the *P/D* ratio of the sparger. A new frequency correlation is proposed in terms of the *P/D* ratio and other thermal hydraulic dimensionless parameters. The dominant frequencies lie in the range of 99 ~ 759Hz.

(3) The *P/D* ratio has a strong influence on pressure oscillation and thermal mixing. As the *P/D* ratio increases, the amplitude of the pressure pulse increases significantly.

(4) The effect of the distribution pattern of the holes on the dominant frequency is relatively smaller than that of the *P/D* ratio.

(5) The thermal mixing effect of the staggered-type spargers is much poorer than that of the parallel-type, specifically when the *P/D* ratio is less than 4.

In the design and/or selection of an optimal sparger related to the DCC phenomena, the thermal mixing effects as well as the characteristics of the pressure pulse, such as amplitude and frequency, should be considered.

Acknowledgment

This work was financially supported for the nuclear R&D program from the Ministry of Science and Technology of Korea.

References

Arinobu, M, 1980, "Studies on the Dynamic Phenomena caused by Steam Condensation in Water," *Proc. of ANS-ASME-NRC Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics*, Vol. 1, pp. 293 ~ 302.

Aya, I., Kobayashi, M., and Nariai, H., 1983, "Pressure and Fluid Oscillations in Vent System due to Steam Condensation, (II) High-Frequency Component of Pressure Oscillations in Vent Tubes under at Chugging and Condensation Oscillation," *J. of Nuclear Science and Technology*, Vol. 20, No. 3, pp. 213 ~ 227.

Bendat, J. S., and Piersol, A. G., 1991, "Random Data Analysis and Measurement Procedures," *John Wiley & Sons*.

Chan, C. K., 1978, "Dynamic Pressure Pulse in Steam Jet Condensation," *Proc. of 6th Int. Heat Transfer Conf.,* Toronto, pp. 395 ~ 399.

Cho, S., Song, C.-H., Park, C. K., Yang, S. K., and Chung, M. K., 1999, "Studies on dynamic pressure oscillation induced by direct condensation of steam discharging through I-type sparger," *Proc. of the KSME thermal engineering division fall meeting*, Sorak Han Hwa resort, Korea, pp.532 ~ 539.

Cho, S., et al., "Multiple-hole effect on the performance of a sparger during direct contact condensation of steam," KSME international journal, Vol. 15, No. 4, pp. 482 ~ 491, 2001

Cumo, M., Farello, G. E., and Ferrari, G., 1978, "Direct Heat Transfer in Pressure-Suppression Systems," *Proc. of 6th Int. Heat Transfer Conf.*, Toronto, Vol. 5, pp. 101 ~ 106.

Damasio, C., Del Tin, G., Fiegna, G., and Malandrone, M., 1985, "Experimental Study on the Unstable Direct Contact Condensation Regimes," *Proc. Of 3rd Int. Topical Meeting on Reactor Thermal Hydraulics*, Newport, Rhode Island, U.S.A., pp.6.C-16.C-8.

Fukuda, S, 1982, "Pressure Variations due to Vapor Condensation in Liquid, (II) - Phenomena at Larger Vapor Mass Flow Flux," *J. of Japanese Atomic Society*, Vol. 24, No. 6, pp. 466 ~ 474.

Simpson, M. E., and Chan, C. K., 1982, "Hydraulics of a Subsonic Vapor Jet in Subcooled Liquid," *ASME J. of Heat Transfer*, Vol. 104, pp. 271 ~ 278.

Sonin, A. A., 1984, "Suppression Pool Dynamics Research at MIT," NUREG/CP-0048, pp. 400 ~421.

The American Society of Mechanical Engineers, 1985, "Measurement Uncertainty - ASME Performance Test Codes, Supplement on Instruments and Apparatus, Part I," ANSI/ASME PTC 19.1-1985

Tin, G. D., Lavagno, E., and Malandrone, M., 1982, "Pressure and Temperature Measurements in a Vapor Condensing Jet," *Proc. of 7th Int. Heat Transfer Conf.*, Vol. 6, pp. 159 ~ 164.

서 지 정 보 양 식

수행기관보고서번호	위탁기관보고서번호	표준보고서번호	INIS 주제코드
KAERI/TR-1984/2001			

제목 / 부제	
증기분사기의 형상이 직접접촉응축 성능에 미치는 영향	
연구책임자 및 부서명 (AR,TR 등의 경우 주저자)	조 석 (열수력안전연구팀)
연 구 자 및 부 서 명	윤영중, 정흥준, 천세영, 백원필 (열수력안전연구팀)

출 판 지	대전	발행기관	한국원자력연구소	발행년	2001/12
페 이 지	25p.	도 표	있음(○), 없음( )	크 기	Cm.
참고사항					
비밀여부	공개(○), 대외비( ), __ 급비밀	보고서종류	기술보고서		
연구위탁기관		계약번호			

초록 (15-20줄내외)

I-형 증기분사기의 압력거동 특성과 열혼합성능을 고찰하기 위해 실험을 수행하였다. 증기분사기의 분사구 이격거리와 분사구 직경비(P/D율)는 2에서 5까지 변화하였다. 실험조건은 응축진동영역으로 제한하였다. 본 연구에서는 분사구 배열을 두가지(parallel 형, staggered 형)로 구분하였다. 최대압력하중은 증기유속과 P/D율에 따라 과냉각수의 온도가 45 ~ 85℃에서에서 관찰되었다. 분사구 배열이 압력하중에 미치는 영향은 P/D에 의한 것보다 작은 것으로 관찰되었다. 주 진동수는 응축수의 과냉각도와 P/D의 증가에 따라 증가하였다. 본 연구에서는 주 진동수에 대한 상관관계식을 증기분사기의 P/D와 다른 열수력적 무차원변수의 항으로 제시하였다.

주제명키워드 (10단어내외)	증기분사기, 압력하중, 열혼합성능, P/D율

<table>
<tr><th colspan="8">BIBLIOGRAPHIC INFORMATION SHEET</th></tr>
<tr><td colspan="2">Performing Org. Report No.</td><td colspan="2">Sponsoring Org. Report No.</td><td colspan="2">Stamdard Report No.</td><td colspan="2">INIS Subject Code</td></tr>
<tr><td colspan="2">KAERI/TR-1984/2001</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Title / Subtitle</td><td colspan="6">Effect on the Performance of a Shape Factor of Sparger During Direct Contact Condensation of Steam</td></tr>
<tr><td colspan="2">Project Manager and Department (or Main Author)</td><td colspan="6">Seok Cho (T/H safety research Team)</td></tr>
<tr><td colspan="2">Researcher and Department</td><td colspan="6">Young-Jung Youn, Heung Jun Chung, Se-Young Chun, Won-Pil Baek (T/H safety research Team)</td></tr>
<tr><td>Publication Place</td><td>Daejon</td><td>Publisher</td><td colspan="2">KAERI</td><td>Publication Date</td><td colspan="2">2001/12</td></tr>
<tr><td>Page</td><td>25p.</td><td>Ill. & Tab.</td><td colspan="2">Yes(○), No ( )</td><td>Size</td><td colspan="2">Cm.</td></tr>
<tr><td>Note</td><td colspan="7"></td></tr>
<tr><td>Classified</td><td colspan="2">Open(○), Restricted( ), ___ Class Document</td><td colspan="2">Report Type</td><td colspan="3">Technical Report</td></tr>
<tr><td colspan="2">Sponsoring Org.</td><td colspan="2"></td><td colspan="2">Contract No.</td><td colspan="2"></td></tr>
<tr><td colspan="8">Abstract (15-20 Lines)
An experimental study has been carried out to investigate the performance of a I-type sparger in view of pressure oscillation and thermal mixing in a pool. Its pitch-to-hole diameter, P/D, varies from 2 to 5. The test conditions are restricted to the condensation oscillation regime. In the present study, two different hole patterns, staggered and parallel types, are employed under the various test conditions. The amplitude of the pressure pulse shows a peak at the pool temperature range of around 45 ~ 85°C, which depends on P/D and the steam mass flux. The effect of the hole pattern on the pressure load is relatively smaller than that of P/D. The results show that the dominant frequency increases with the subcooling temperature of pool water and P/D. A correlation of the dominant frequency is proposed in terms of the pitch-to-hole diameter ratio and other dimensionless thermal hydraulic parameters.</td></tr>
<tr><td colspan="2">Subject Keywords (About 10 words)</td><td colspan="6">Sparger, Pressure Load, Thermal Mixing, Pitch-to-Hole Diameter Ratio</td></tr>
</table>