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Power Reactor and Nuclear Fuel Development Corporation

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PRELIMINARY RESULTS OF GAS INJECTION INTO SODIUM FLOWING IN A 37-PIN BUNDLE

by

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ABSTRACT

Out-of-pile experiments were conducted to evaluate the thermal and hydrodynamic effects due to gas injection into sodium flowing in a 37-pin bundle, which consisted of a central gas-injection pin, seven electrically heated pins and other dummy pins. Thermocouples were installed on the cladding of heated pins.

The first series of experiments were carried out without gas injection to establish base cases and to evaluate the effect of mixing due to spacer wires. The experimental results agreed well with the predictions by the NORMAL code which considers the effect of mixing due to spacer wires.

The second series of experiments were conducted with injecting argon gas transiently or continuously through a small nozzle (0.2 ∿ 0.3 mm in diameter) of the gas-injection pin. In the transient injection experiment rapid temperature rises due to gas blanketing were observed on the surfaces of the heated pins at the axial position where gas was injected. In the continuous injection experiments, however, the measured wall temperature rises were small and well within tolerable limits.

INTRODUCTION

The amount of fission gas in fuel pins of a liquid metal cooled fast breeder reactor (LMFBR) increases as the fuel pins are irradiated. The pressure of fission gas reaches to approximately 60×10^5 N/m^2 at the end-of-life of MONJU's fuel pin. If the cladding of a fuel pin fails, the fission gas may be injected rapidly into the coolant. The fission-gas release in LMFBR's subassemblies can potentially result in fuel failure propagation through two distinct mechanisms - (a) temperature transients in the cladding of adjacent fuel pins, exceeding the threshold temperature for failure at the operating conditions; and (b) transient mechanical loads on adjacent fuel pins due to pressure pulses.

From the standpoint of reactor safety, fission-gas release experiments were carried out with water as coolant in Japan since 1966.

The first series of experiments(1) concerned the single pin failure in stagnant or flowing water for observing the behavior of gas bubbles injected from the ruptured cladding. From the analysis of high-speed movie films, it was concluded that the severe movement of the ruptured pin and the generation of shock waves are caused by the rapid rupture speed (less than 0.1 msec).

The next series of experiments(2) were conducted in a mock-up subassembly with flowing water in order to investigate the degree of mechanical damage to adjacent pins and to the wrapper tube. The mechanical effects observed were rather insignificant.

The last series of experiments with water(3) were performed in a subassembly with an electrically heated pin in order to investigate the effects of gas blanketing. The transient temperature rise at the heated surface was insignificant, if the normal flow of coolant was maintained.

Gas jet impingement tests with sodium were performed at ANL using a three-pin test section.(4) In ANL's tests the gas was continuously released from a needle existing between two heated pins upon a heated pin and the cladding temperature rise of the impinged pin was measured with many sets of parameters - gas type, needle internal diameter, heat flux, coolant mass flow rate, gas plenum temperature, gas plenum pressure, and relative position of the gas release needle with respect to the internal thermocouple of the heated pin. The measured temperature rise was ∿240°C at 250 w/cm^2, and it was concluded that extensive and rapid pin-to-pin failure propagation by fission-gas release is unlikely.

Although these experiments were performed in detail, it is yet unadequate to estimate the gas-release phenomena in LMFBR subassemblies, because gas may be injected transiently and spreads more widely over the subassembly. The degree of transient temperature rises and the extent of fuel pins influenced by the released gas must be investigated in transient experiments with sodium in a more multi-pin bundle. The pressure pulse and the change of flow velocity at the moment of gas release can be also measured only by transient gas-release experiments.

Gas-release experiments in a 37-pin bundle with sodium started at PNC in 1974. In the experiments the gas was injected transiently or continuously. The continuous gas-release experiments compensate the limited number of transient experiments.

The present paper gives preliminaly results of these recent experiments at PNC, mainly concerning to the pin surface temperature rises caused by gas injection.

EXPERIMENTAL EQUIPMENT

The experiments were carried out in the SIENA loop installed at Oarai Engineering Center, PNC. Figure 1 gives schematic representations of the test section and the cross section at the axial location of the gas-injection point. The 37-pin bundle were consisted of a central gas-injection pin, seven electrically uniformly-heated pins and other dummy pins. The arrangement of heated and other pins are shown in the figure. The diameter of each pin was 6.5 mm. With the exception of the gas-injection pin, each pin was wrapped with a 1.3 mm diameter wire clock-wise in the flow direction at a 264.8 mm pitch. The distance between pin centers (i.e. the pin pitch) was 7.9 mm. The 37-pin bundle was surrounded by a hexagonal tube of 50.4 mm in inner flat-to-flat distance.

The sodium entered through an entrance tube, then flowed upward in the bundle. Argon gas, simulating fission gas, was supplied from the top of the gas-injection pin and injected into flowing sodium through a small nozzle of the gas-injection pin in the direction shown in the figure.

To keep heat losses to a minimum, the outer wall of the test tube was insulated with a compensating heater and thermal insulator.

The thermocouples were provided at various points along the test section. The pin thermocouples T-11, T-12, ... and T-73 measured the temperatures of the outer surface of heated pins. Each thermocouples which had 0.3 mm in diameter was embedded in the outer surface of the sheath. The local temperatures in the individual coolant channels were measured by 1.3 mm OD thermocouples T-108-1, ... and T-108-7, the leads of which form the spacer wires of heated pins. The sodium velocities at the inlet and outlet were measured by the electromagnetic flowmeters F-106 and F-107, respectively. Strain-gauge-type pressure transducers P-106 and P-107 were provided at the inlet and outlet to measure the pressure pulse caused by gas injection. The gas plenum pressure was measured by a pressure transducer P-204.

Potential-tap-type void meters (VoT-1, ..., VoT-14) were used for estimate the void fraction in the test section.

EXPERIMENTAL PROCEDURE

At first all the thermocouples were calibrated before the experiments and checked while the sodium was circulated isothermally. The experimental procedure was as follows: (a) The high-temperature and high-pressure argon gas was supplied from gas-supply and-heating system (see Fig. 2) to the gas-injection pin, then the valve V-601 was closed so as to inject a constant volume of gas in a transient experiment. (b) Before gas was injected, temperature readings were taken at the predetermined velocity and power level of heated pins to take a base case and to compare these results with that measured during the gas was injected. (c) A transient gas-release experiment started with striking the upper end of a rod contained in the gas-injection pin to break a rupture film at its lower end (see Fig. 3). All the signals from instruments attached to the test section were recorded by analog data recorders as well as digital data acquisition system until the gas plenum pressure decreased surfficiently. (d) The valve V-601 was opened and gas was injected continuously. Temperature readings were taken after reaching a new steady-state condition.

EXPERIMENTAL RESULTS

Wall temperature profile for steady single-phase flow

In the series of experiments temperature readings were taken without gas injection to take the base cases. The experimental results were compared with the analytical results calculated by the NORMAL code. The NORMAL code is a revised version of ORRIBLE(5) which is a computer program to predict the flow and temperature distributions for steady single-phase flow through a bundle. Figure 4 shows a comparison of measured wall temperatures of heated pins and those predicted by the NORMAL code for the same operating condition. Calculations were made with several sets of parameters (C_T: turbulent crossflow coefficient, C_D: pressure diversion crossflow coefficient, C_S: sweeping corssflow coefficient). The experimental results agreed well with the calculated wall temperature for C_T=0.001 and C_S=1. The effect of the parameter C_D on the temperature distribution was a little.

Transient gas-injection experiments

Figure 5 shows typical results of a transient gas-release experiment (Run No. GR-1). In the experiment the linear heat rate of heated pins was 157 w/cm, the sodium flow velocity before gas injection was 4.84 m/s , the sodium inlet temperature was 268°C and the gas-injection nozzle diameter was 0.3 mm. The gas temperature was almost same as that of sodium. As the gas was injected with sonic velocity, gas plenum pressure decreased from 33.8×10^5 N/m^2 gradually. Rapid temperature rises due to gas blanketing were observed on the wall of heated pins at the axial position where gas was injected (T-22, T-52). Especially T-22 showed the maximum temperature rise of 87°C. On the other hand, although thermocouple T-32 was attached on the nearest surface to the gas-injection nozzle, the measured temperature rise was small. At the moment of gas injection the outlet velocity increased to the peak value of approximately 5.4 m/s, then decreased to 5.04 m/s with small oscillation. The inlet velocity decreased to 4.78 m/s due to gas injection. From these values the void fraction after gas injection at the cross section where the outlet flowmeter was installed was estimated at about 0.05. Pressure pulse was seen with the inlet pressure transducer as well as with the outlet pressure transducer.

Figure 6 shows the results of another transient experiment (Run No. GR-2). The experimental conditions were almost same as in the experiment Run No. GR-1 with the exception of the nozzle diameter (0.2 mm) and the initial gas plenum pressure. In this case rapid temperature rises were not seen. Only the thermocouple T-32 showed the temperature rise of 22°C.

Any signs that the pin bundle has been failed is not shown after six transient gas-injection experiments. This will suggest that the failure of adjacent pins due to transient mechanical loads accompanied with gas injection is unlikely.

Continuous gas-injection experiments

Figure 7 gives the wall temperature rises of heated pins Tw for various gas plenum pressure Pg. The data were also shown for the case of no gas injection. The nozzle diameter was 0.2 ∿ 0.23 mm, the gas pressures were 13×10^5 N/m^2, 30.5×10^5 N/m^2 and 62.5×10^5 N/m^2, the equivalent mass flow rates of gas were 0.08 g/s, 0.25 g/s and 0.55 g/s respectively. In the case of higher inlet sodium velocity v = 4.81 ∿ 4.90 m/s (Fig. 7(a)), no influence of gas injection was seen at the cross section of 37 mm upstream from the gas-injection plane. At the 3 mm downstream wall temperature rises was seen on No.2 and No.3 pins, and at the 43 mm downstream the wall temperature rise was also seen on the No.1 pin. These temperature rises were attributed to the diffusion of gas bubbles in the downstream. In the case of lower velocity v = 0.46 ∿ 0.49 m/s (Fig. 7(b)), however, the wall temperature rises could be seen even in the 37 mm upstream from the gas-injection plane.

Figure 8 shows that the wall temperature rise increased linearly as the linear heat rate of heated pins was increased. If the measured wall temperature rises are applied to the reactor conditions the temperature rises due to continuous gas release will be small and well within tolerable limits.

CONCLUSIONS

Preliminary gas-injection experiments were conducted in a 37-pin bundle. From these experiments and their comparison with analytical calculations yielded the following conclusions.

(1) In the transient gas-injection experiments rapid temperature rises due to gas blanketing were observed.

(2) In the continuous gas-injection experiments, the measured surface temperature rises were small and well within tolerable limits.
(3) The measured temperature distributions in the pin bundle without gas injection agreed well with the predictions by the NORMAL code which considers the effect of mixing due to spacer wires.

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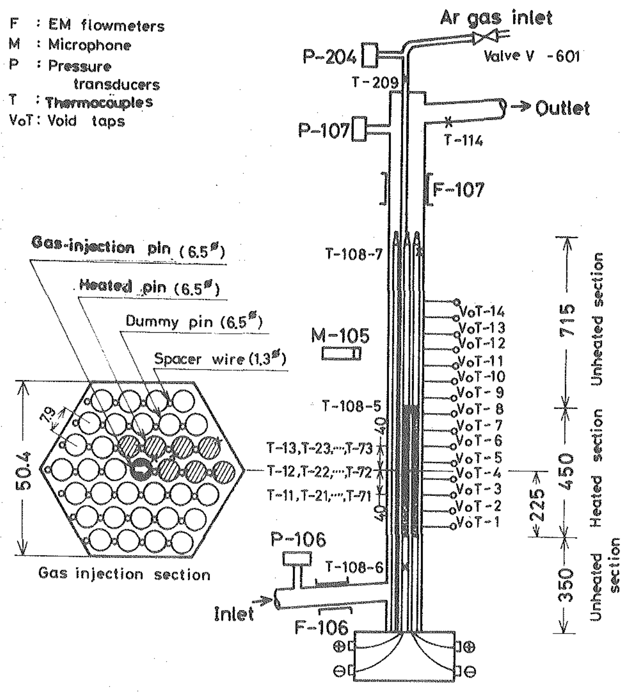


Fig. 1 Test section with a 37-pin bundle (PNC-FS-173)

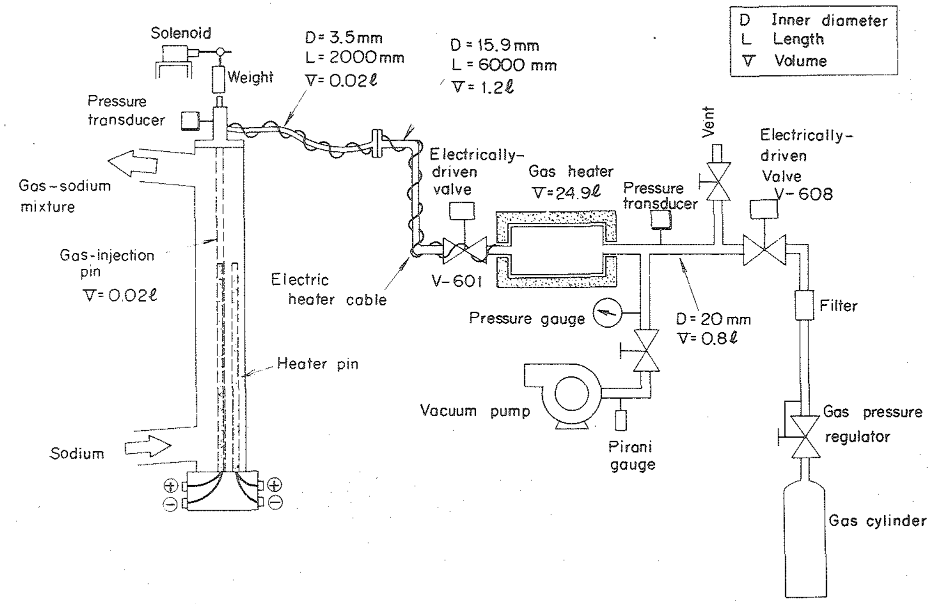


Fig. 2 Gas-supply and -heating system (PNC-FS-220)

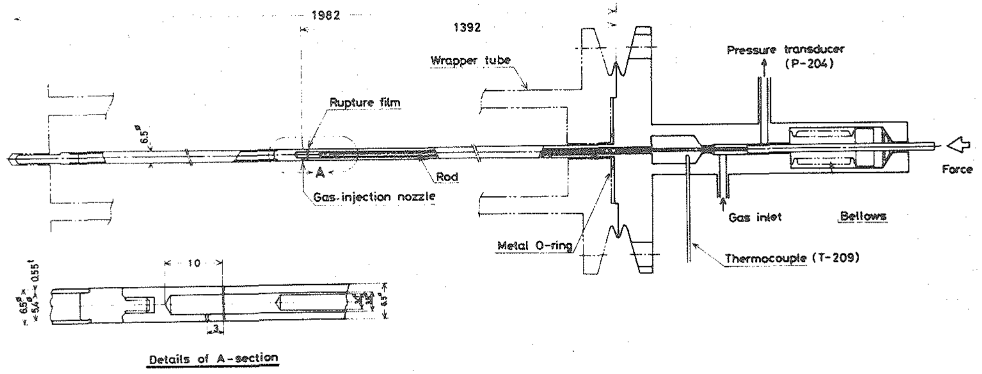


Fig. 3 Gas-injection pin (PNC-FS-177)

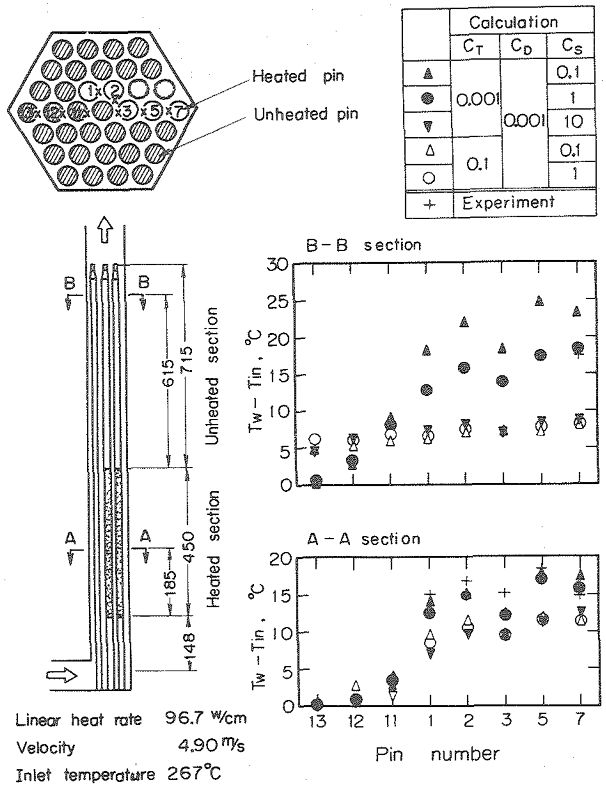


Fig. 4 Comparison of experimental results of the wall temperature rise with that calculated by the NORMAL code for Run No. 37H-115 (PNC-FS-276)

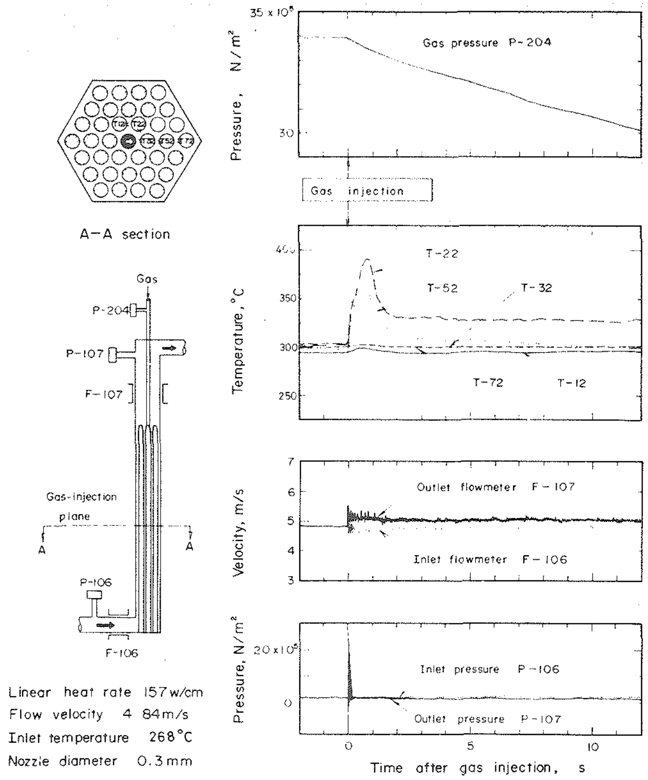


Fig. 5 Typical signals from thermocouples, flowmeters and pressure transducers for a transient gas-release test; Run No. GR-1 (PNC-FS-188)

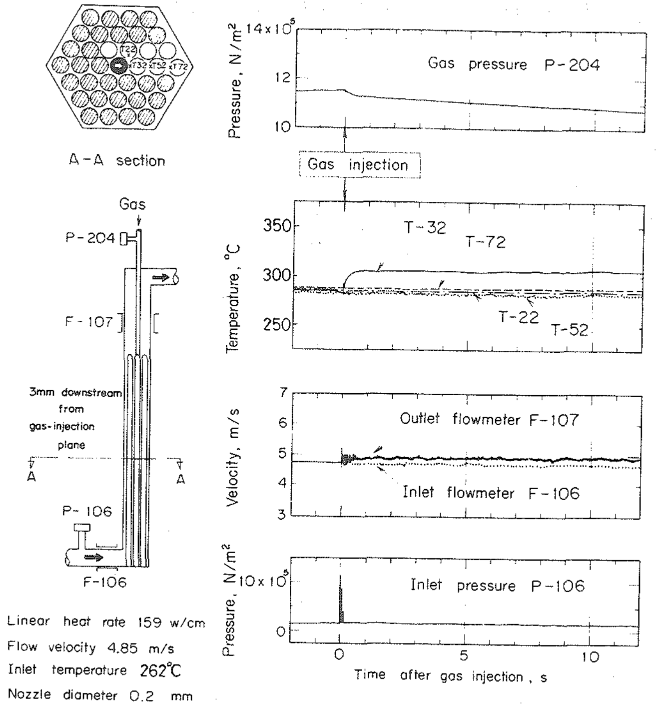
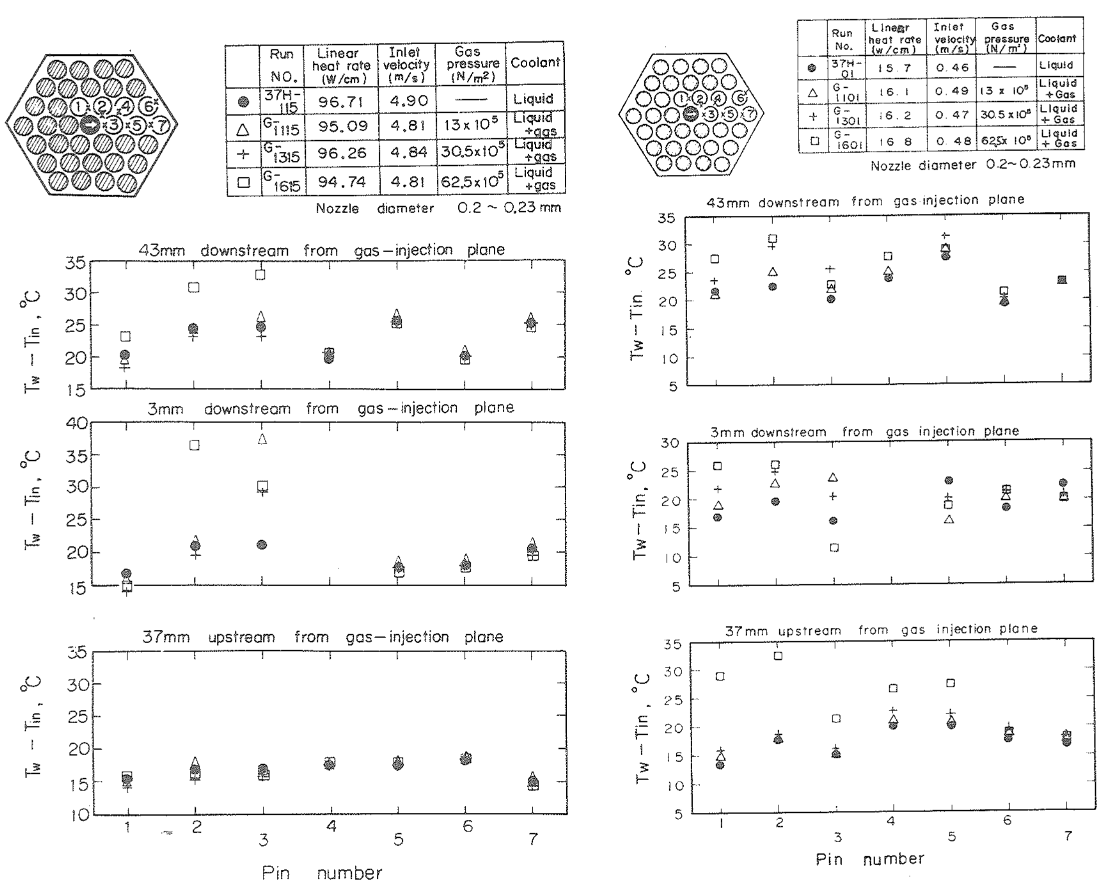


Fig. 6 Typical signals from thermocouples, flowmeters and pressure transducer for a transient gas-release test; Run No. GR-2 (PNC-FS-199)



(a) v = 4.81∿4.90 m/s

(b) v = 0.46∿0.49 m/s

Fig. 7 Effect of gas plenum pressure on wall temperature rise for continuous gas-injection tests (PNC-FS-228, 229)

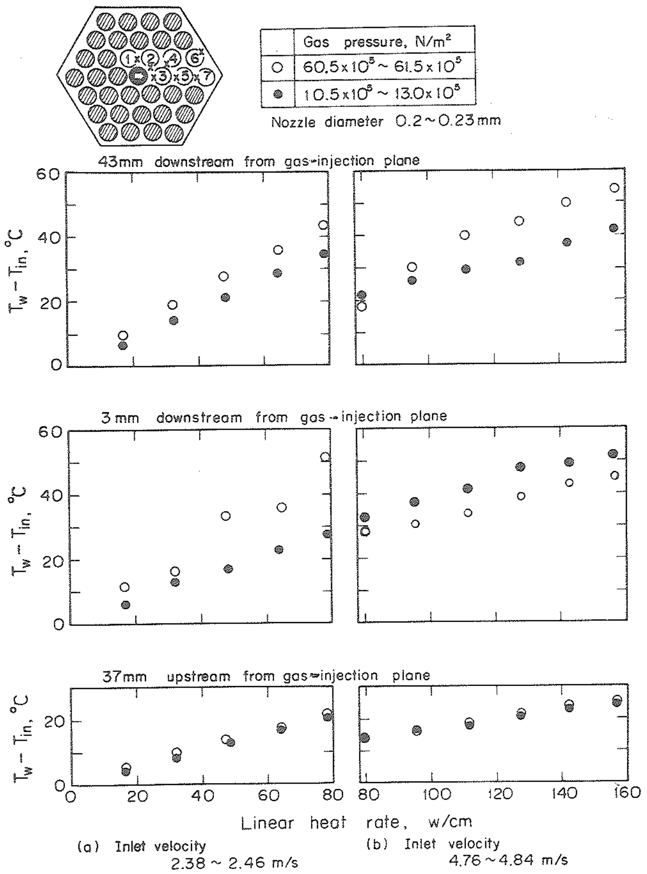


Fig. 8 Effect of linear heat rate on wall temperature rise for continuous gas-injection tests, No.3 pin (PNC-FS-218)