# Analysis of Rewetting Time and Temperature Distributions During Cooling Process in Vertical Rectangular Narrow Channel


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## Abstract

Cooling process to analyze effect of gap size to rewetting time and temperature distributions were studied from transient temperature of surface plate. It as result of experiment using two vertical plate with the initial temperature about 600$^\circ$C. Debit and temperature of cooling water are 0,09 L/s and saturated temperature. The gap sizes were changed from 1 mm, 2 mm, and 3 mm. As the results showed that the smaller the gap size, the longer the rewetting time. Pattern of temperature distribution is similar at initial condition for all of gap sizes and the smaller the gap sizes, the longer the time of decreasing temperature.



**Keywords:** Cooling process, rewetting time, temperature distribution.



## Abstrak

Proses pendinginan untuk menganalisa pengaruh ukuran celah terhadap waktu pembasahan dan distribusi temperatur diamati dari transient temperatur permukaan plat. Penelitian dilakukan menggunakan dua plat vertikal dengan temperatur awal 600$^0$C. Debit dan temperatur air pendingin adalah 0,09 L/s dan temperatur jenuh. Ukuran celah divariasikan dari 1 mm, 2 mm dan 3 mm. Hasil penelitian menunjukkan bahwa semakin kecil ukuran celah semakin panjang waktu rewetting. Pola distribusi temperaursama pada kondisi awal untuk semua ukuran celah, semakin kecil ukuran celah semakin panjang waktu untuk penurunan temperatur.



**Kata kunci:** Proses pendinginan, rewetting time, distribusi temperatur


## 1. INTRODUCTION

Cooling process is one of the important processes for system sustainability. It is a process of decreasing temperature, and it is occurred heat transfer from medium with higher to lower temperature. In cooling process, transient and distribution temperature need to be known to determine the rewetting point. Cooling process phenomena can be known in severe accident reactor nuclear Three Miles Island 2 (TMI-2). TMI-2 nuclear accident is one of the cases about cooling process in narrow channel. It is formed between debris and wall of reactor pressure vessel (RPV). Based on Juarsa [2] opinion that the debris has been cooled by water in the bottom reactor and it can not exit from RPV wall, so reactor condition can be controlled. When the debris move to bottom (see Figure 1), then a part of cooling water volume is moving to upper part and evaporation process is occurred. The vapor is moving to upper part but the cooling water is continually flowing to the bottom, then it is occurred counter current flow (CCF) between vapor and cooling water (see Figure 1). The first contact of cooling fluid to wall surface is known as rewetting point. It is indicated by drastically drop temperature of wall surface. It is one of the important roles to maintain the condition of wall surface, and then melting point can be controlled. In other parts, temperature distribution of wall surface need also to be considered, so the temperature of each point in the wall surface can be known to maintain the temperature in order to unclose to the melting point. So, the severe accident of reactor nuclear can be avoided.

Some experiments about cooling process in narrow channel have been conducted by researcher. Zhang et al [3] was conducted the experiment in vertical annulus narrow channel with the water as cooling fluid based on single heated case. It is using the 300 mm length, the gap sizes were changed from 0.5 mm, 1.0 mm, 2.0 mm, 4.0 mm, and 7.0 mm. The initial temperature of plate surface was varied from 500 $^o$C, 650 $^o$C, and 800$^o$C. The results are the smaller the gap size, the longer the rewetting time and rewetting time of 4.0 mm is very closing to 7.0 mm gap size. It is caused by effect of Counter Current Flow Limitation (CCFL).


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Juarsa and Antariksawan [1] were conducted the experiment with some of the variable is similar to Zhang et al [3] experiment. Juarsa and Antariksawan were proposing the rewetting pattern of cooling process in annulus vertical narrow channel with the 1.0 and 4.0 mm gap sizes, 300 mm heated length, and saturated water as cooling fluid. The initial temperature of heated surface is 800$^o$C. For 1.0 mm gap size, the rewetting is started from upper, then lower, and finish at midle part of the heated surface. In other parts, for 4.0 mm gap size, rewetting process is started from lower, then midle, and finish at upper part of the channel.

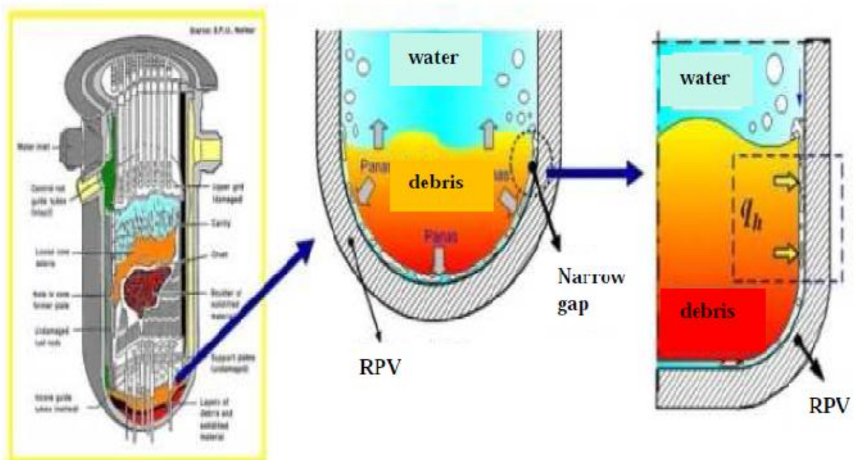


Figure 1. Narrow gap in the nuclear reactor [2]

Next, experiment Riyono et. al [2] is similar to Zhang et.al [3] and Juarsa and Antariksawan [1]. Riyono et. al [2] was using annulus as geometry channel, with the 800 mm heated length, 1.0 mm gap size, and 650$^o$C initial temperature of surface. Water as cooling fluid with the temperatures were varied from 75$^o$C, 85$^o$C, and 95$^o$C. As the results that rewetting time at 75$^o$C is longer than 85$^o$C dan 95$^o$C temperature of water. This experiment show that change phase at 85$^o$C and 95$^o$C are easier than 75$^o$C temperature of water. So, it is causing film boiling existence is shorter than 75$^o$C temperature of water.

The previous experiments are indicating that the experiments about cooling process in the narrow gap are one of the complex analyzes because it is influenced by some variables. Therefore, in this study is to know effect of gap size to rewetting time and temperature distributions in vertical rectangular narrow channel. Rewetting time is analyzed from transient temperature of heated plate and then temperature distributions as the contour of the temperature of plate at certain time.

## 2. METHOD

### Experimental apparatus

This experiment is a joint two facilities. They are Untai Uji Beta (UUB) and HeaTiNG-02 (see Figure 2). UUB is used to set-up flow rate and temperature of cooling water before it is flowed to the channel. UUB has a centrifugal pump for setting-up flow rate of the cooling water and circulating it, flow meter is used to know mass flow rate of the cooling water, pre heater is used to increase the cooling water temperature, thermocouple is used to measure the temperature, and some of valves are used to open or close the cooling water flow. HeaTiNG-02 is the main test section. It has main and cover plates stainless steel with 8 mm and 3 mm thickness, 1100 mm length, 50 mm width. Narrow gaps (δ) of the main and cover plates are changed from 1.0 mm, 2.0 mm and 3.0 mm. The main and cover plates have six chromel-allumel thermocouples (TC) (see Figure 3). It is used to measure of temperature during heating and cooling process. Figure 2 show the schematic apparatus.

WinDAQ T1000 data acquisition system (DAS) is used to measure plate temperature during process with 1 data per second. Slide regulator with the 25 kW maximum power is used to change power input during heating process until the plate temperature is about 600°C. The power input was gradually increased for uniform plate temperature.

### Experimental procedures

The experiment is started by setting up the gap size. The range is shown in Table 1. Bottom part is opened, so the pressure system is about atmospheric pressure, and then the plates are heated by ceramic heater until the initial temperature is about 600°C. If it has been reached, the ceramic heater is switched off, then 0.09 L/s and about 90°C of cooling water that controlled at UUB is flowed to the channel. If all of the temperatures are closing to 90°C, the experiment is stopped.

Table 1. Experimental variable

| Variable | Value | | |
|---|---|---|---|
| | I | II | III |
| Gap Size (mm) | 01.00 | 02.00 | 03.00 |
| Initial temperature ($^oC$) | 600.0 | 600.0 | 600.0 |
| Cooling water mas flow rate (L/s) | 00.09 | 00.09 | 00.09 |
| Cooling water temperature ($^oC$) | 90.00 | 90.00 | 90.00 |

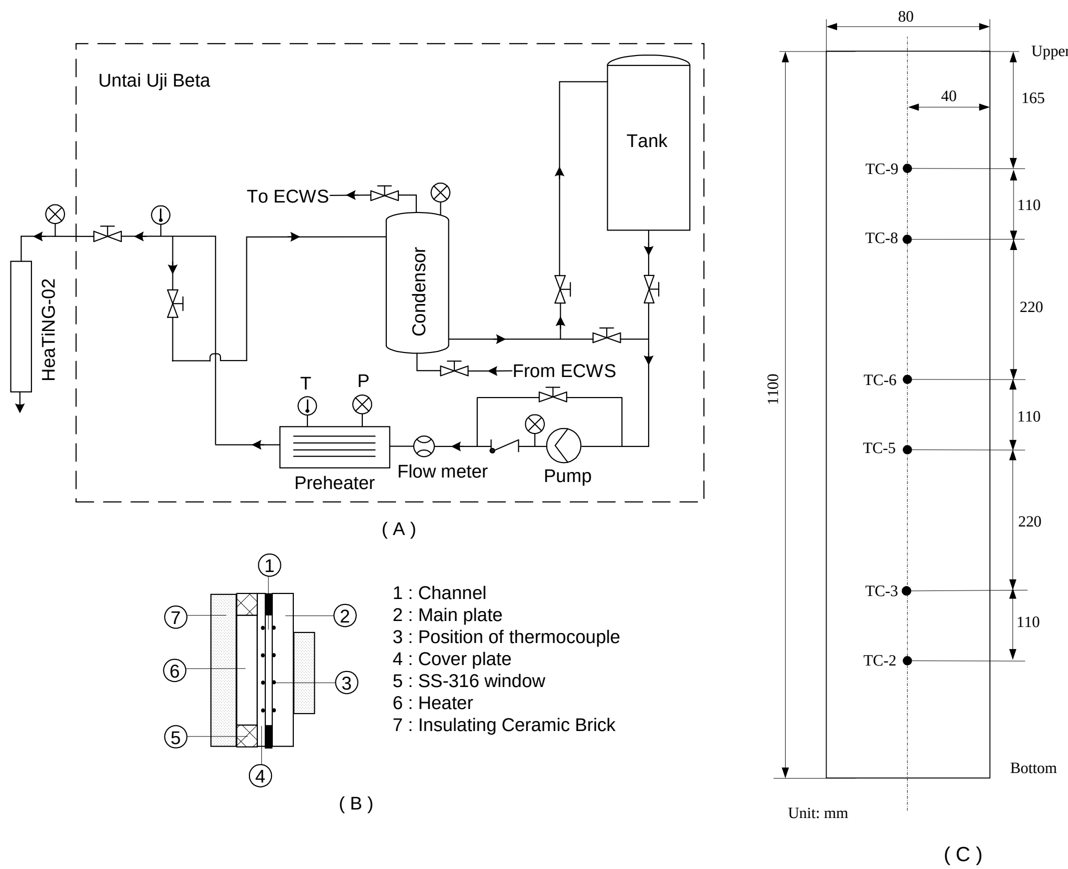



Figure 2. (A) Schematic apparatus, (B) Detail HeaTiNG-02, (C) Thermocouple position on main and cover plate

## 3. RESULTS AND DISCUSSION

### Transient temperature

Transient temperature is the different temperature to the time. The temperature at each time will be captured by TC and then recorded by DAS and finally it can be read at personal computer. The temperature in the plate was plotted as Figure 4. It is representing TC-6 on the midle of plate with the initial temperature about 600$^o$C. In the initial condition, it has not been occurred contact between water and plate surface because in the plate is existed by vapor blanket, the radiation heat transfer is occurred but the convection have not been occurred. It is caused by vapor blanket that have high pressure was restricting to contact the cooling water to surface plate. The first point to its contact is known as rewetting point and the time is known as rewetting time. In the rewetting point is starting point of heat transfer. From initial to rewetting point is known as film boiling regime. The next condition is drastically droping temperature. It is an indicator of rewetting point. After rewetting point, the convection heat tranfer is occurred, the decreasing of the temperature is not so drastic until the temperature is about 90$^o$C. It is the finally of experiment.

**Rewetting time**

Figure 4 show that decreasing temperature is occurred in the plate. Plate temperature is slightly decreasing before and after rewetting point. Rewetting point can be kown from transient temperature. It is a condition when the cooling water contact to the surface plate and it is indicated by drastically drop of temperature. Figure 4 also shown that rewetting time on δ = 1 mm is about 280 seconds, on δ = 2 mm is about 130 seconds and on δ = 3 mm is about 105 seconds. From the value, it is indicating that the smaller the gap size, the longer the rewetting time. It is caused by the smaller the gap size, the higher the vapor pressure in the channel. Hence, the smaller mass flow rate of water cooling, the longer the time of vapor contraction in the channel. In the condition, penetration of water in the channel is resisted by vapor that existed on the surface of plate, so the longer the contact time of cooling water to plate surface. Next condition, temperature is not significantly decreasing because the deference temperature between plate surface and cooling water is not so high.

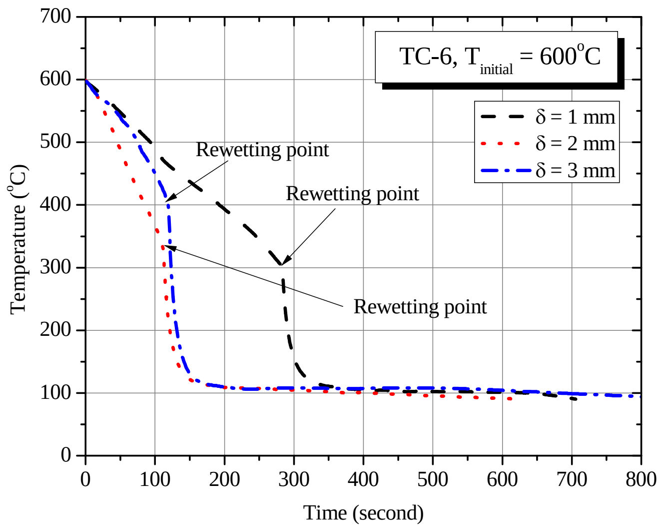



Figure 4. Transient Temperature TC-6

**Temperature distributions**

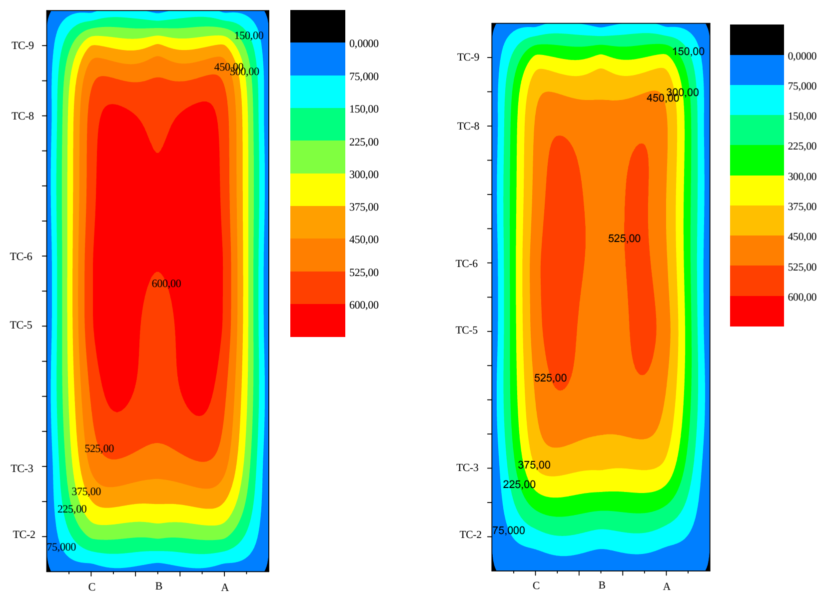
Temperature distribution was maded from data of plate temperature. It was recorded by DAS and then plotted by Origin computer program with the contour type. So, the results are showed in Figure 5 up to Figure 7. In the initial condition, the pattern of temperature distribution is similar for all of the gap size and show that the air was flowing to the channel from the bottom part of plate. It is caused by open channel on the bottom part ans it is indicated by plate temperature in the bottom part is smaller than other. The phenomena is similar therefore the gap sizes was changed. In the midle part of the channel is the highest temperature and it is closing to the initial temperature about 600$^o$C.

**For δ = 1 mm:**

At the 100$^{th}$ seconds was occurring the decreasing of temperature for all of the thermocouple. The cooling water was flowing in the center of the plate, so the temperature is smaller than side part. In this time, the cooling water has not been contacted to the plate. The radiation heat transfer is only exist in this time and the vapor contraction is still occurring. Vapor contraction is caused by counter current flow of vapor and cooling water. The vapor was flowing to the upper part and the cooling water was flowing from the upper part. The longer of the time of vapor contraction, the longer of the time to decreasing temperature. After occurring of the vapor contraction, the cooling water will contact to the surface plate and the rewetting phenomenon is accured. So, the longer time of the vapor contraction, the longer time to get the rewetting point and the longer time to decreasing plate temperature. In other hand, the temperature in bottom part is the smallest because it is caused by flowing air to the channel from the bottom part.

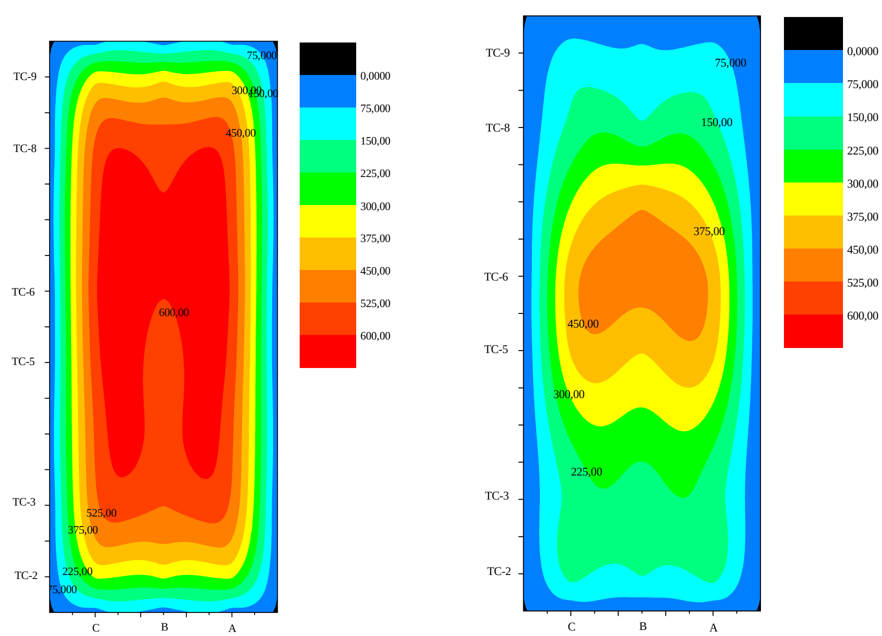
**For δ = 2 mm:**

Different condition is occurred at the 100th seconds. From Figure 6 is shown that the bottom temperature is smaller than the middle part of plate. It is indicating that the cooling water is flowing through side part to contact to the bottom part. In other hand, the temperature middle part is the highest than other parts. In this time, the decreasing temperature is caused by radiation from vapor to the cooling water and the rewetting phenomenon was occured on the upper and bottom parts of the plate only. In the condition, the convection heat transfer from plate to cooling water is occured. In the midle part, the rewetting time is occured about on 280 seconds (like as figure 4).




(a) (b)

Figure 5. Temperature Distributions at $T_{initial}$ = 600°C for δ = 1 mm,
(a) The1st seconds, (b) The 100th seconds




(a) (b)

Figure 6. Temperature Distributions at $T_{inital}$ = 600°C and δ = 2 mm,
(a) The 1st seconds, (b) The 100th seconds

**For δ = 3 mm:**

Pattern of temperature distribution at δ = 3 mm is similar with δ = 2 mm. It is a indication that decreasing temperature at δ = 3 mm is closed to δ = 2 mm. At δ = 3 mm, quantity of air and cooling water are so high to flow in the channel because the gap size is the highest than other. It is causing the smaller time of vapor contraction, and it is implicating on rewetting time. Finally, it will influence to decreasing the temperature. The phenomenon on the bottom part of the channel is not consistent. In the 100$^{th}$ seconds, the rewetting was occured on the bottom and upper part. So, from all of the temperature distributions are known that the higher the gap size, the faster the decreasing temperature. It is predicted by the smaller the gap size, the larger the contraction of vapor. It is also caused by the higher the effect of CCFL, then the longer the time contact to surface plate. So, decreasing plate temperature need a long time.

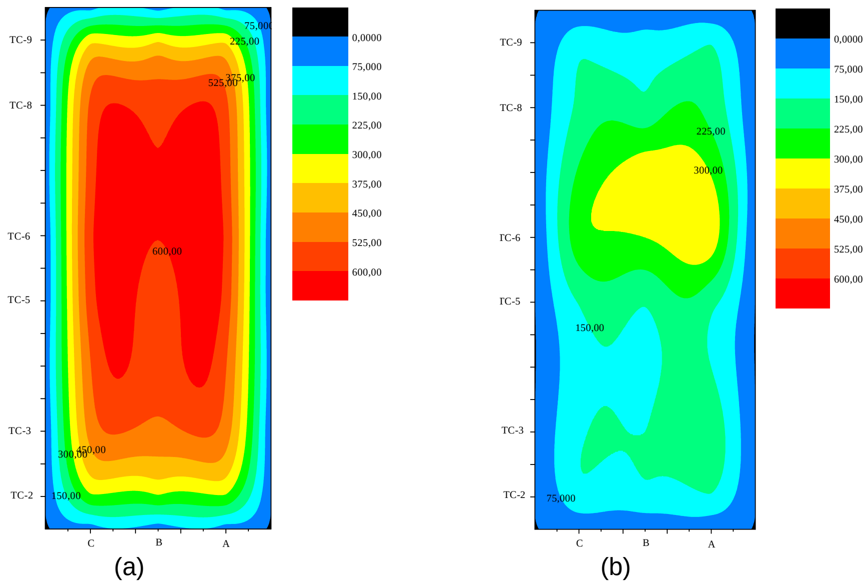



Figure 7. Temperature distributions at $T_{initial}$ = 600°C and δ = 3 mm,
(a) The 1$^{st}$ seconds, (b) The 100$^{th}$ seconds

## 4. CONCLUSIONS

From the discussion above can be concluded that:

a. The smaller the gap size, the longer time to get the rewetting point.
b. Pattern of temperature distribution is similar at initial condition for all of gap sizes
c. The smaller the gap sizes, the longer the time to decreasing plate temperature.

## ACKNOWLEDGEMENT

Thank you very much to Mr. Ismu Handoyo, Mr. Kiswanta, Mr. Joko P, Mr. Ainur R, and Ririn F for their help and carring attitudes. Thanks to Ministry of Research and Technology, Indonesia Government for Incentive Research Grant 2009. Thanks to Thermo Hydraulic research group, Center of Reactor Technology and Safety Nuclear, Indonesia National Nuclear Energy Agency, Tangerang, Indonesia for their support activity.

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