Residual Coolant Quantity in High Pressure Vessel of PWR–440

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Abstract

The dynamic behavior of the remaining thermal carrier at different interval times in the high pressure cylinder of a VVER – 440 MW reactor has been studied, when the sudden leakage occurred in the first cooling loop. The study included the effect of the diameter and the location of the leakage hole, in addition to the temperature of the thermal coolant within the first cooling loop prior to the start of the leakage process.

An experimental equation was developed for the distance of the remaining thermal carrier within the high pressure cylinder as a function of time based on the relative diameter, the relative height of the coolant flow and the relative temperature of the thermal coolant. Important conclusions are made that could contribute to building nuclear safety systems for reactors of the type (Pressurized Water Reactor), PWR– 440 with power of 440 Mw.

1 -Introduction

The end of the seventh (in the 1970s) decade and subsequent decades witnessed a "wide" development in the field of nuclear safety of nuclear facilities, especially after the events of the USM-3 and Chernobyl, Russia. The construction of nuclear safety systems requires practical and theoretical information related to the dynamics of leakage of the heat carrier during a defect in the system of the first cycle or in the reactor cylinder itself. But this process occurs in stable conditions, so when the pressure of the coolant and its temperature and humidity change, these studies are characterized by complexities accordingly, some of which appeared in research [1-2]. It can be observed that this study cannot be observed in the nuclear reactor, therefore a variety of systems are set up to represent a case similar to the first cooling cycle of the station PWR.

The process of electing the specifications of this session is carried out to reflect the capacity of the reactor being studied. The reactor pressure vessel is considered to be the most reliable component of pressurized water reactors. The condition of the reactor pressure vessel is a major limiting factor for the operating life of a power plant [3]. The research discussed two important factors that are based on the study of nuclear safety, namely the time of experimentation and the residual quantity of the thermal carrier after the end of the leakage process.

The purpose of the election process is to reflect the capacity of the 440 MW reactors being

studied. Two important factors on which the study of nuclear safety is based are studied:

the trial time, and the amount of residual coolant quantity after the leakage process [4].

But the research leaves out the dynamics of the thermal carrier, specifically the amount of heat transfer remaining in the high pressure vessel (the important part of the system) at different moments of time. Taking into consideration that the behavior of nuclear fuel at the core of the PWR-440 reactor when a sudden leakage occurs, studying this research will focus on finding a practical method how to build an emergency cooling system, and forming a theory to determine the amount of residual coolant in the high pressure cylinder at certain moments.

2 - Humidity change

When an error occurs in the first cooling cycle (one of the main tubes or high pressure cylinder), a sudden drop in pressure will be noticed [2]. In order to study the dynamics of the coolant there, the high pressure cylinder was filled with water under pressure of P_0 equal to 12.3 MPa and a temperature of 558 K^0(285C^0) to represent the specifications of the 440 MW PWR reactors[5-6]. The process of flow is then carried out from both the upper tube, the lower tube one. Several pressure drop gauges were installed along the column height to measure the coolant mass in the high pressure vessel [7]. Thermal carrier flow height values, was changed from 5 mm to 4 mm, and studying the flow process of two other temperatures, 523 K^0 and 473K^0 , was also re-examined.

The pressure value of the cylinder decreases immediately whenever if the flow value becomes slightly lower than the saturation pressure of that thermocouple that the thermal carrier had before the flow occurred (Fig. 1). In less than half a second, the boiling process begins to flow and the two-phase stream flows out of the cylinder, and the vapor ratio changes inside the vessel as it increases over time.

3 - Amount of residual coolant

Severe accident management strategies may be derived from many level actions, such as (a) depressurizing(reducing pressure) the reactor coolant system to prevent high pressure failure of the reactor pressure vessel and direct containment heating and (b) depressurizing the vessel to prevent its failure by excess pressure or to prevent basement failure under elevated containment pressure [8].

The distribution of the high pressure cylinder into a part occupied by the steam and the other operated by the liquid[2-9-10] helped to find the quantity of the thermal carrier inside the cylinder from the moment of boiling until the final point of it, using the following relations:

$$M = F \int_0^H \gamma(h) dh \qquad \ldots\ldots\ldots.(1)$$

Where:

F: cross section area of the vessel (m^2) at height H(m).

$\gamma(h)$: Coolant density (g/cm^3) at height h from the vessel, which depends on vapor ratio value ψ, vapor density γ' and water density γ'' at saturation line which can be found with the

help of the following relationship[11]:

$$\gamma(h) = [1 - \psi(h)]\gamma' + \psi(h)\gamma'' \qquad \ldots\ldots\ldots\ldots(2)$$

The thermal carrier flow speed G(t) can be used to find the residual thermal carrier value[5], i.e.:

$$M(t) = \int_0^t G(t) dt$$

$$M(t) = M_0 - G(t) \qquad \ldots\ldots\ldots\ldots\ldots.(3)$$

Where

M_0: the total quantity of the coolant inner high pressure vessel (kg).

The following relation could be used to find G(t) values[12-13]:

$$G(t) = 0.2948 G_0 H^{-3/2} T^{1/3} \exp(-10.61 Ha) \exp[-11.22 (HT)^{-1} \exp(-14.44 a)]\, \tau \ldots.(4)$$

In which:

$$G_0 = 447 F \sqrt{P_2 - P_1} \qquad \ldots\ldots\ldots\ldots\ldots(5)$$

P_1, P2: pressure, inner and outer the vessel

$$a = d - 0.0323 \qquad \ldots\ldots\ldots\ldots\ldots(6)$$

$$d = \frac{d_t}{D_0} \qquad \ldots\ldots\ldots\ldots\ldots.(7)$$

d_t: Diameter of the leakage hole and D_0 is total diameter of the vessel

$$H = \frac{h_t}{H_0} \qquad \ldots\ldots\ldots\ldots.(8)$$

h_t: leakage hole height and H_0 is the total height of vessel

$$T = \frac{285}{T_0} \qquad \ldots\ldots\ldots\ldots\ldots.(9)$$

$$\tau = \frac{t}{t_0} \qquad \ldots\ldots\ldots\ldots\ldots(10)$$

T_0: coolant temperature inner the vessel before leakage at time T

t_0: Total time of the experiment

Equation (4) is accepted for the following ranges [12]:

$0.0323 \le d \le 1.456$

$0.66 \le H \le 0.8$ and

$1.0 \le T \le 1.425$

Results and Discussion

The total mass of the coolant inside the vessel at 558 K^0 and 12.3 Mpa is equal about 120 kg. Equation (3) can be used to find the amount of heat carrier inside the cylinder as a function of time for leakage diameter of 32 mm. Figure(1) shows a good correlation between practical and computational results. It appears from this figure that the boiling process starts after the beginning of leakage by a short interval time of a bout (0.3-0.4) sec.

Fig.(2), shows the dynamics of changing the vapor ratio within the vessel for different time periods. The portion to the left of the curves represents steamed area, while the right part represents the water. It should be noted that when these curves were drawn, it was assumed that that the top of the cylinder was occupied from the beginning of the boiling process until the end, while the ratio of steam in the bottom of the cylinder is zero. This assumption is a logical result of the rise of the steam bubbles to the top. A diameter of 32-mm was chosen in Fig.(1) because it represents the explosion of the first-cycle cooling tube (500 mm).

Fig.(3) represents the change of the coolant mass in the vessel as a function of time, to flow from the bottom tube of the cylinder out of a hole of 32 mm and a temperature of 558 K^0. This figure shows that the amount of heat carrier decreases faster in the first moments of the beginning of the boiling process. This can be explained by the high value of the difference between the pressure inside and outside the vessel at these moments, as this difference increases the speed of thermal flow outside the cylinder. Over time, the value of this difference decreases and the flow speed decreases as well.

Figure (4) shows the results of the calculations of the amount of remaining coolant for a number of leakage pipe diameters from the bottom tube of the cylinder indicated temperature and pressure. It is shown that "the convergence of account results and measurements is also good. Figure (5) shows the change in the quantity of the thermal carrier in the pressure.

cylinder for different temperatures, while Figure (6) shows how much the amount of coolant remaining inside the cylinder is greater when the leakage occurred in the hot line of the leakage itself.

Referring to Figure (1), it has been shown that, boiling process begins again in a short period of time, after the start of the leak in (0.2 - 0.4) seconds when the leakage diameter is 10 mm. This time period constitutes a few thousand-parts of the total leakage time. Thus, it could be stated that the water that is discharged during that time period (the period of leakage of the heat carrier without saturation) constitutes a "small" part of the flow process.

The results display the percentage of the leakage coolant of different diameters, showing that this percentage ranges between 0.25% and 1.12%. Continuing fluid loss decreases the primary pressure to the secondary side pressure if the leakage removes enough energy from the primary system [14]. The results accumulated are of the current time t and the relative t/τ of the residual coolant in the high pressure vessel for three different diameters and different temperatures for the bottom and upper leakage. Besides, the results of the amount of residual heat carrier received are attributed to the size of the cylinder for different diameter of the leakage hole of the upper and lower tube at three different temperature levels of the coolant prior to the start of the flow process.

Conclusions

The study of the dynamic flow of the coolant in the high pressure cylinder, similar to a PWR reactor of 440 MW, leads to the following conclusions:

1 - The amount of thermal carrier leaking from the cylinder increases by increasing the temperature of the thermal carrier inside the cylinder prior to the leakage process (when the leakage hole is firmly fixed and positioned). This may be due to the fact that the sharp drop in pressure in case of leakage causes the boiling water carrier to boil at the same temperature as it was prior to leakage. However, the higher the temperature, the greater the pressure difference between the vessel and the air pressure, and thus the less amount of the remaining cylinder will be.

2. The velocity of the coolant from the upper tube is significantly lower than in the lower tube, although the distance between the tubes is relatively small (3.10 mm) and can be explained by the following:

The ratio of steam at the beginning of the flow process, where the level (the illusion) separates the water and steam above the upper tube of the flow, is greater than the proportion of steam in the lower levels of steam bubbles that rise to the top causing less flow than the heat carrier and the amount of thermal carrier remaining in the cylinder less.

3 - The speed of the flow of the thermal carrier increases by increasing the diameter of the leakage hole for all cases, so that the amount of coolant remaining at any time point was lower whenever the flow hole was bigger.

4. The first cooling cycle is the primary loop, or the reactor coolant system. This is a closed loop system that circulates coolant through the nuclear core and cooled fuel rods in it. The ratio of the amount of thermal carrier remaining in the total volume of the cylinder decreases by increasing the diameter of the leakage hole and increasing the temperature of the thermal carrier prior to the leakage process. This also depends on the location of the flow pipe.

The effect of the leakage diameter on the residual coolant quantity can be explained as follows: fluid droplets carried by the leaky steam when the leakage hole is big; are larger. While the transmission of these droplets decreases with the leaky current of the small leakage diameters. Therefore we can say that there is a little transmissions and leakage with small diameters because large droplets can’t pass through it and there is no absorption.

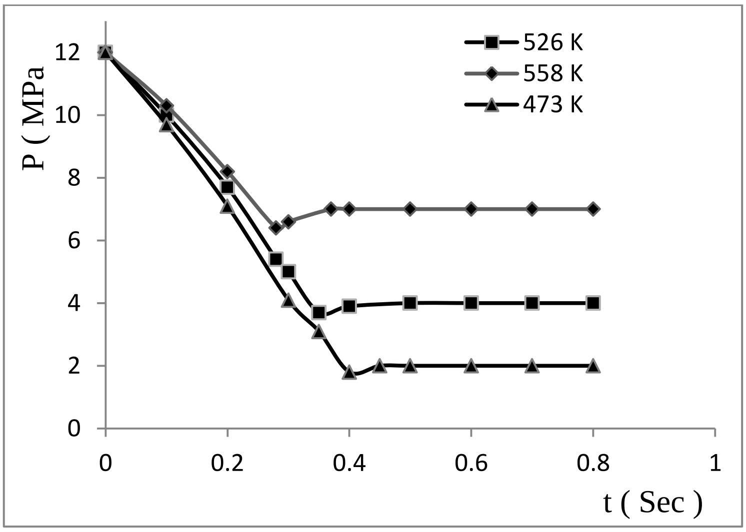

Figure (1): Pressure gradient for different temperatures (leakage hole 10mm)

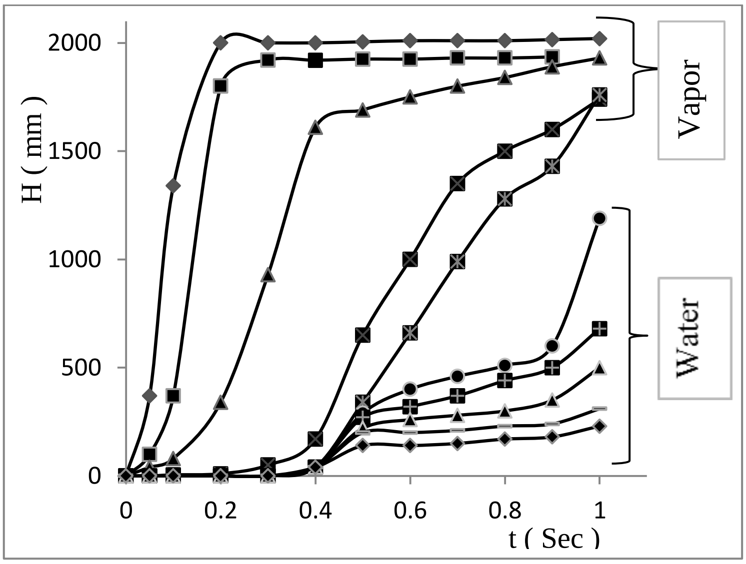

Figure (2): Vapor distribution inner the vessel (32 mm hole) diameter and temperture 558K°

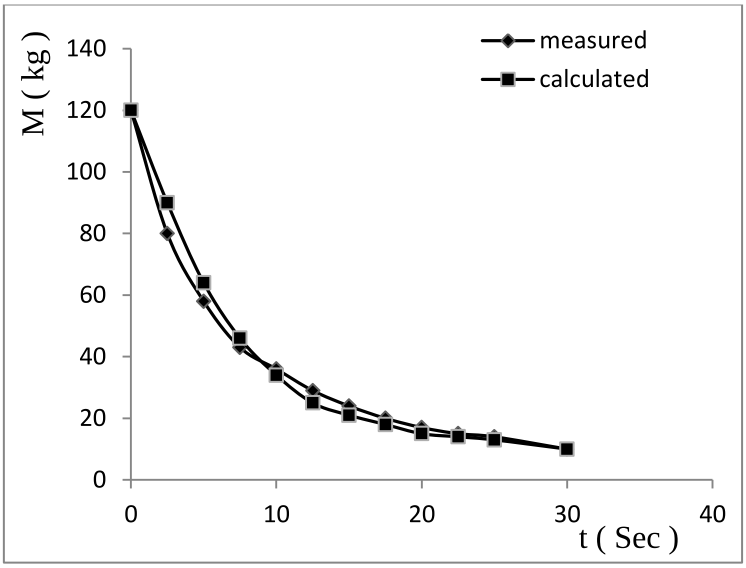

Figure (3): Coolant quantity in the high pressure vessel at different times (leakage hole diameter 32mm, T=558K^0 and P=12.3 MPa for lower leakage)

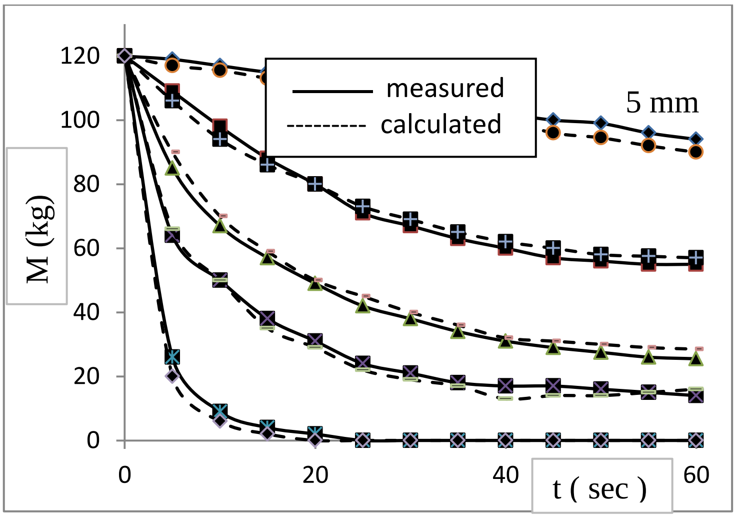

Figure (4): Residual coolant quantity in the vessel for different times (lower pipe with T=558 K^0)

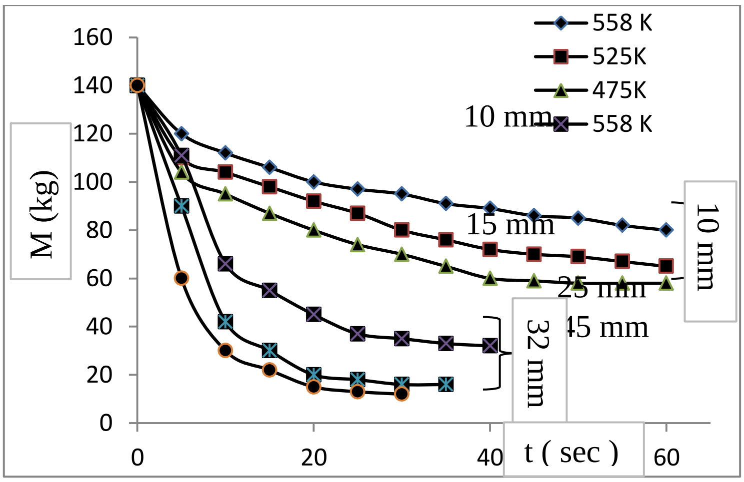

Figure (5): Coolant temperature effect on residual coolant quantity for two different diameters (leakage is from lower pipe)

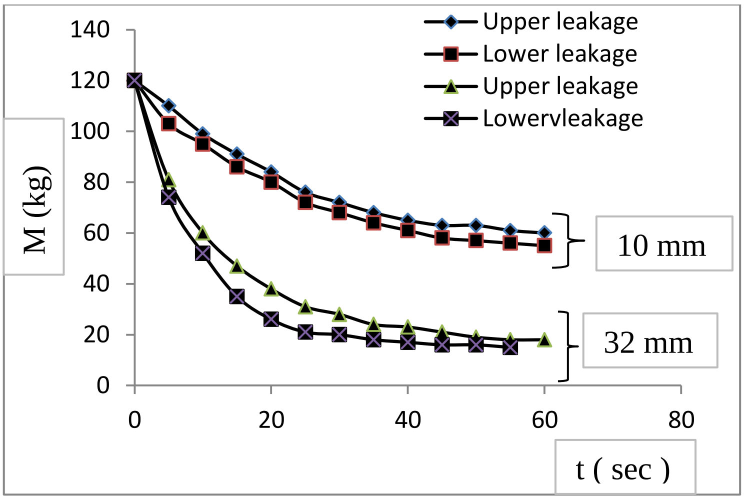

Figure (6): Leakage location effect on remainder coolant quantity in high pressure vessel for two different pores (T = 558 K^0)

CONFLICT OF INTERESTS

There are no conflicts of interest.

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كمية الناقل الحراري المتبقي في اسطوانة الضغط العالي في PWR–440

الخلاصة

تناول البحث بصورة مفصلة دراسة ديناميكية سلوك كمية الناقل الحراري المتبقي في لحظات زمنية محتلفة في بقدرة ٤٤٠ ميكاواط عند حدوث التسرب المفاجىء في VVER – 440 MW في اسطوانة الضغط العالي دورة التبريد الاولى. وتضمنت الدراسة تأثير قطر فتحة التسرب وموقعه ودرجة حرارة الناقل الحراري داخل دورة التبريد الاولى قبيل بدء عملية التسرب. وتم وضع معادلة تجريبية في ابعاد كمية الناقل الحراري المتبقي داخل اسطوانة الضغط العالي كدالة زمنية تعتمد على القطر النسبي والارتفاع النسبي للتدفق ودرجة الحرارة PWR النسبية للناقل الحراري. واختتم باستنتاجات هامة يمكن ان تسهم في بناء منظومات السلامة النووية لمفاعل من نوع بقدرة ٤٤٠ ميكاواط.

الكلمات الدالة:, المبرد, التسرب, اسطوانة الضغط العالي، VVER – 440