

# A Comparison in Thermal-Hydraulics Analysis of PWR-1000 Using Fixed and Temperature Function of Thermal Conductivity

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### A COMPARISON IN THERMAL-HYDRAULICS ANALYSIS OF PWR-1000 USING FIXED AND TEMPERATURE FUNCTION OF THERMAL CONDUCTIVITY.

A study to analyze the influence of the fuel-cladding's thermal conductivity on the sub-channel of pressurized water reactor 1000 (PWR-1000) using COBRA-EN computer code was conducted. The purpose of this research is to gain complete understanding of sub-channel thermal-hydraulic aspects related to fuel performance, especially the appropriate range of thermal conductivity of UO<sub>2</sub> fuel ( $k_f$ ) and zircaloy-4 cladding ( $k_c$ ) in order to obtain an accurate sub-channel analysis related to its safety behavior. The research was conducted by comparing the calculation with the combination values of the fixed  $k_f$  and  $k_c$ , as well as the calculation using  $k_f$  and  $k_c$  as temperature function. The fixed  $k_f$  using in this calculation were 5.26 W/m.K, 3.85 W/m.K, 3.60 W/m.K, 3.18 W/m.K, 2.90 W/m.K, 2.53 W/m.K and 2.34 W/m.K, while the  $k_c$  were 13.0 W/m.K, 15.57 W/m.K, 16.75 W/m.K, 17.94 W/m.K and 18.69 W/m.K. The maximum fuel center line temperature using  $k_f$  and  $k_c$  as temperature function (MATPRO) for hot sub-channel was 1717.65°C and taken as the reference in accepting the calculation result using fixed thermal conductivity. The analysis was accepted, if the deviation between both temperature was in the range of -10% to 10%. This analysis results for hot sub-channel was accepted for the calculation using value of  $k_f$  in the range of 3.18 - 2.90 W/m.K for all variation value of  $k_c$ . While the calculation using value of  $k_f$  of 2.53 W/m.K was accepted for value of  $k_c$  in the range of 16.76 - 18.69 W/m.K.

### ABSTRAK

#### PERBANDINGAN ANTARA ANALISIS TERMOHIDROLIKA PWR-1000 MENGGUNAKAN KONDUKTIVITAS TERMAL TETAP DAN SEBAGAI FUNGSI TEMPERATUR.

Telah dilakukan penelitian untuk mengetahui pengaruh nilai konduktivitas termal kelongsong dan bahan bakar dalam analisis termohidrolika sub-kanal reaktor air tekan 1000 (PWR-1000) menggunakan kode COBRA-EN. Penelitian ini bertujuan untuk mendapatkan pemahaman yang komplit pada aspek termohidrolika sub-kanal yang berkaitan dengan unjuk kerja bahan bakar, khususnya rentang nilai konduktivitas termal bahan bakar UO<sub>2</sub> ( $k_f$ ) dan bahan kelongsong zircaloy-4 ( $k_c$ ) yang tepat agar diperoleh analisis yang akurat. Penelitian dilakukan dengan cara membandingkan perhitungan menggunakan kombinasi nilai  $k_f$  dan  $k_c$  yang konstan (tetap), dengan perhitungan menggunakan  $k_f$  dan  $k_c$  sebagai fungsi temperatur. Nilai  $k_f$  konstan yang digunakan sebesar 5,26 W/m.K, 3,85 W/m.K, 3,60 W/m.K, 3,18 W/m.K, 2,90 W/m.K, 2,53 W/m.K dan 2,34 W/m.K, sedangkan nilai  $k_c$  sebesar 13,0 W/m.K, 15,57 W/m.K, 16,75 W/m.K, 17,94 W/m.K dan 18,69 W/m.K. Temperatur maksimum pusat bahan bakar untuk sub-kanal panas menggunakan  $k_f$  dan  $k_c$  sebagai fungsi temperatur (MATPRO) sebesar 1717,65°C dan diambil sebagai acuan penerimaan hasil perhitungand engan nilai konduktivitas termal konstan. Analisis diterima, jika deviasi antara kedua temperatur berada antara -10% sampai 10%. Hasil analisis pada sub-kanal panas dapat diterima untuk perhitungan menggunakan  $k_f$  antara 3,18 dan 2,90 W/m.K untuk seluruh variasi nilai  $k_c$ . Sedangkan perhitungan dengan  $k_f$  sebesar 2,53 W/m.K dapat diterima untuk nilai  $k_c$  antara 16,76 dan 18,69 W/m.K.

**Kata kunci:** perbandingan, termohidrolika, konduktivitas termal, tetap dan fungsi temperatur.

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## 1. INTRODUCTION

The analysis of core and sub-channel of a Nuclear Power Plant (NPP) has been

performed in order to gain complete understanding of core thermal-hydraulic aspects related to fuel performance and NPP

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safety behavior. This analysis is conducted by a calculation using computer codes to obtain a prediction of thermal hydraulic performance of a NPP. An accurate prediction of thermal hydraulic performance of a NPP is crucial in its design and operation for both economic and safety reasons [1] especially the prediction of the peak temperatures of the fuel rods and coolant. These predictions depend on fuel meat, cladding and coolant outlet temperature in the steady state or transient conditions [2].

Many researches on thermal-hydraulic of a NPP had been conducted by using fixed value for thermal conductivity. These researches were done on Pressurized Water Reactor 1000 MWe (PWR-1000) and Advanced PWR-1000 (AP1000) reactor core using COBRA-EN code related to evaluation on sub-channel design thermal-hydraulic [3], grid-spacer effect [4] and the effect of radial-axial power fluctuations [5]. In this study, COBRA-EN code used thermal conductivity data of  $\text{UO}_2$  fuel of  $3.60 \text{ W/m}\cdot^\circ\text{C}$  [3,4] and the thermal conductivity of Zircaloy-4 cladding of  $18.69 \text{ W/m}\cdot^\circ\text{C}$  [3-5]. COBRA-EN code is also used on capability enhancement for VVER reactor calculation [2], deterministic optimum loading pattern [6], thermal-hydraulics modeling of nanofluids [7], sub-channel analysis of nano fluid [8] and other research in VVER-1000 reactor [9-11].

In an NPP, the heat generation in the fuel is influenced by the position of fuel assemblies on the reactor core. Heat generation in the fuel assemblies at central position of core tends to be higher than at the edge position in radial position, and tends to be higher than in the top and bottom of active core in axial position. The highest, averages and lowest heat generation of fuel assemblies each known as hot channel, average channel and cold channel, respectively. The heat generation in the fuel assemblies and the physical properties of the fuel, cladding and coolant will determine their temperatures. These physical properties such as the specific heat capacity ( $C_p$ ) and the coefficient of thermal conductivity ( $k$ ) of fuels and claddings are the ability of fuel and cladding to transfer heat to coolant and influenced by the temperature itself. Consequently, the differences of heat generation and physical properties will result the temperature

differences in the fuel meat, cladding and coolant.

In order to obtain an accurate PWR-1000 sub-channel thermal-hydraulic analysis related to safety behavior, the analysis of core and sub-channel thermal-hydraulic of a PWR-1000 was conducted in which the core calculation was done by using COBRA-EN code. This analysis is performed in order to gain an understanding of sub-channel thermal-hydraulic aspect related to fuel performance in effective heat transfer processing, especially the appropriate range of thermal conductivity of  $\text{UO}_2$  fuel and Zircaloy-4 cladding. The analysis of sub-channel thermal-hydraulic using codes often encountered obstacles, e.g. the limitation of code in calculating physical properties as a temperature function such as conductivity and heat capacity of fuel and cladding. This limitation affects accurate calculation results. Therefore, the sensitivity analysis of fuel and cladding thermal conductivity on sub-channel thermal-hydraulic characteristics of PWR-1000 was conducted to obtain more accurate analysis results. The previous study discussed that the increase in the fixed value of the thermal conductivity of the fuel provided insignificant effect on reducing the peak cladding temperature during the accident [1]. In this research, the analysis was accepted if deviation between temperature values using fixed and temperature function of thermal conductivity was in the range of -10% to 10% [12] to avoid inaccuracy.

The purpose of this research is making the sub-channel thermal-hydraulic analysis of AP1000 accurate, with the emphasizing on the effect of fuel and cladding's fixed thermal conductivity value on temperature distribution of coolant, cladding and fuel. The accuracy of the analysis was shown from the comparison the results between the calculation using fixed value of thermal conductivity and the calculations using thermal conductivity as temperature functions. The accurate analysis using fixed thermal conductivity were needed for future research, because several codes for analyze the transient condition, such as EUREKA code, are only able to use fixed thermal conductivity as the input. Hence, the accurate analysis using fixed thermal conductivity is very

important. This analysis was conducted on steady state nominal power condition. The calculations using fixed value of thermal conductivity were conducted using COBRA-EN code, by inputting proper value. While the calculation using temperature function of thermal conductivity was conducted using MATPRO + COBRA-EN code, by inputting negative value.

## 2. THEORY

### 2.1. Description Of PWR-1000 Fuel Matrix

PWR-1000 core [12,13] are composed of 193 fuel assemblies which each fuel assembly contains 264 fuel rods with 3.66 m of active length, 24 guide tubes (guide thimble) and 1 tube containing instrumentation, 2 grid holders (at the bottom and top of the fuel assemblies) and 8 spacer grids along the active fuel rods, 3411 MWt power capacity, system pressure of 15.5 MPa, inlet coolant temperature of 288°C and effective coolant flow rate of  $12.47 \times 10^6$  kg/(m<sup>2</sup>h). In general, PWR is operated safely if the fuel meat temperature is about 30% below its melting temperature (2594°C) as the worst conditions of the fuel, while the minimum Departure from Nucleate Boiling Ratio (DNBR) limit are different from one PWR type to another. In PWR-1000, the minimum DNBR is 2.17 [13,15]. The rod dimension of PWR-1000 is shown in Table 1.

In this research, analysis of PWR-1000 sub-channel thermal-hydraulic was performed

Table 1. Rod Dimension of PWR-1000 [13,14]

NPP type	PWR-1000
Fuel assembly size (cm x cm)	21.40 x 21.40
Total of rods	264
Space between <i>rod</i> center or pitch (mm)	12.6
Outside cladding diameter, OD (mm)	9.4
Cladding thickness (mm)	0.610
Gap thickness (mm)	0.084
Pellet diameter (mm)	8.0
Fuel active length (m)	3.66
Pellet density (% theoretical density)	95

by making a comparison between the calculation using variations in fixed thermal conductivity as input data versus thermal conductivities as a function of temperature. The data used in this research are the thermal conductivities of Zircaloy-4 cladding and uranium dioxide fuel at a certain temperature during reactor operation obtained from previous studies. In the previous study using the fixed value of the thermal conductivity of the fuel provided insignificant effect on reducing the peak cladding temperature during the accident [1]. Therefore, this research needs to be performed because the valid range of thermal conductivity which involves conductivities as a function of temperature will be very useful in the analysis of advanced thermal-hydraulic of a nuclear power plant, especially in over power and/or transient condition and provides more accurate analysis results. The analysis were focused on the influence of the thermal conductivity of UO<sub>2</sub> fuel and the Zircaloy-4 cladding in the PWR-1000 core thermal-hydraulic, with the emphasizing on the effect of fuel and cladding's conductivity value on coolant temperature distribution, the temperature of outer and inner cladding, the temperature of outer and the center line of the fuel, and the DNBR. The calculation was performed at a steady state nominal power by comparing the results between the calculation using variations in the fixed value of thermal conductivity cladding and fuel as input data and the calculations using conductivity as a function of temperature. The calculations of fixed value of thermal conductivity were conducted using COBRA-EN code while the calculations of the conductivity as a temperature function were performed using COBRA-EN code + MATPRO [12]. As a hypothesis, several thermal-hydraulic analysis using fixed thermal conductivity were not valid for analysis due to the fuel center line temperature which out of the range compared to the ones using thermal conductivity as temperature function.

### 2.2. Description of COBRA-EN Code

The COBRA-EN code provides a capability for the thermal-hydraulics analysis of light water reactor (LWR) type NPPs

(both Boiling Water Reactor (BWR) and Pressurized Water Reactor (PWR)) on steady-state and transient conditions. This code used channel and sub-channel analysis approach to determine the coolant flow and enthalpy distribution in rod bundles. The input data are the linear power, fuel rod geometry, thermal properties of fuel and cladding, primary system exit pressure, inlet mass flux for fuel channels and inlet coolant temperature. While the output data are the distribution of enthalpy, core pressure drop, coolant flow rate, fuel and cladding temperatures, heat flux and DNBR.

Table 2. Specific heat capacities of Zircaloy-4 [12]

Temperature (K)	Specific heat capacity (J/kg K)
300	281
400	302
640	331
1090	375
1093	502
1113	590
1133	615
1153	719
1173	816
1193	770
1213	619
1233	469
1248	356

There are two options when inputting the thermal properties of fuel and cladding as the input data of COBRA-EN, whether (1) the values of specific heat and thermal conductivities of fuel and cladding were fixed, or (2) the values of specific heat and thermal conductivities of fuel and cladding as a temperature functions (the value changed based on temperature reference). Specific heat and thermal conductivities of fuel and cladding as a temperature functions can be calculated using subroutine of MATPRO[15] and has been used in analysis of VVER[11] and LWR[13,14,16]. The LWR fuel rod cladding (zircaloy-2 or -4) have been modeled for inclusion in the MATPRO[12] material properties subroutine. Modeling approaches range from the experimental data with linear interpolation or extrapolation to a semi empirical expression suggested by theory. The data of specific heat capacity of Zircaloy-4 in MATPRO was described in Table 2.

From Table 2, the standard error for data points between 300 and 800 K were 1.1

J/kg.K, for data points between 800 and 1090 K were 2.8 J/kg.K, and 10.7 J/kg.K for data points between 1090 and 1310 K[12].

The heat transfer from the fuel pellet to the reactor coolant depends partly on thermal conductivity of the cladding. In MATPRO, the correlation of thermal conductivity for temperature less than 2098 K was described in Equation 1. The standard error of the thermal conductivity of Zircaloy in Equation 4 was 1.01 W/m.K[12,13]. Each notation in the equations were described in nomenclature.

$$k_{Zry} = 7.51 + 2.09 \times 10^{-2} T_c - 1.45 \times 10^{-5} T_c^2 + \dots \dots + 7.67 \times 10^{-9} T_c^3 \tag{1}$$

where  $k_{Zry}$  is thermal conductivity of Zircaloy (W/m.K);  $T_c$  is Cladding temperature (K).

In MATPRO, the specific heat capacity of fuel was modeled empirically as functions of four parameters: composition, temperature, molten fraction and oxygen to metal ratio. The correlation for specific heat of  $UO_2$  was shown in Equation (2)[12,13].

$$C_p = \frac{K_1 \theta^2 \exp(\theta / T_f)}{T_f^2 [\exp(\theta / T_f) - 1]^2} + K_2 T_f + \dots \dots + \frac{K_3 E_D}{RT_f} \exp(-E_D / RT_f) \tag{2}$$

where  $C_p$  is specific heat capacity of  $UO_2$  (J/kg.K);  $K_1$  is constant = 296.7 (J/kg.K);  $K_2$  is constant =  $2.43 \times 10^{-2}$  (J/kg.K<sup>-2</sup>);  $K_3$  is constant =  $8.745 \times 10^7$  (J/kg);  $T_f$  is Fuel temperature (K);  $E_D$  is activation energy for Frenkel defect (J/mol);  $R$  is universal gas constant = 8.3143 (J/mol.K).

It should be noted that the constants of  $K_1$ ,  $K_2$ ,  $K_3$ ,  $\theta$  and  $E_D$  were determined by Equation (2) and only valid at fuel temperatures greater than 300K. The specific heat capacity correlation of  $UO_2$  has standard error of  $\pm 3$  J/kg.K[12,13].

The thermal conductivity correlation of uncracked  $UO_2$  fuel in MATPRO was shown in Equation (3)[12,13].

$$k_f = \left( \frac{D}{1 + (6.5 - 0.00469T')(1 - D)} \right) \times \dots$$

$$\dots \times \left( \frac{C_V}{(A + BT'')(1 + 3e_{th})} \right) + 5.2997 \times 10^{-3} \times \dots \quad (3)$$

$$\dots \times T_f \left[ \exp(-13358/T_f) \right] \times \left\{ 1 + 0.169 \left[ (13358/T_f) + 2 \right]^2 \right\}$$

where  $k_f$  is thermal conductivity of  $UO_2$  (W/m.K);  $D$  is the fraction of theoretical density (-);  $T'$  is porosity correction ( $T' = 6.50 - T_f^*(4.69 \times 10^{-3})$  for temperature < 1364 K,  $T' = -1$  for temperature > 1834 K, and  $T'$  was found by interpolation for temperature in the range 1364 to 1834 K);  $A$  is a factor proportional to the point defect contribution to the phonon mean free path (m.s/kg.K). The correlation used for this factor was  $0.339 + 12.6 \times \text{absolute value}(2.0 - O/M \text{ ratio})$ ;  $T_f$  is fuel temperature (K).

The fixed value of thermal conductivity of  $UO_2$  fuel ( $k_f$ ) in this calculation was computed using correlation as described in Equation 4 [12,13].

$$k_f = \frac{1}{11.8 + 0.0238T_f} + 8.775 \times 10^{-13} T_f^3 \quad (4)$$

where  $k_f$  is thermal conductivity of  $UO_2$  (W/m.K);  $T_f$  is Fuel temperature (K).

### 3. METHODOLOGY

The main problem in thermal-hydraulics analysis using fixed thermal conductivity is how to determine the range of fixed thermal conductivity of fuel and cladding, so the analysis result was accepted. Consequently, analysis using fixed thermal conductivity of fuel and cladding should be compared to analysis using thermal conductivity as temperature function.

In order to obtain the accurate thermal-hydraulic analysis of the PWR-1000 using COBRA-EN code, several steps are performed in this computation. First step was the preparation of input data using channel and sub-channel approach to determine the coolant flow and enthalpy distribution in rod

bundles. The input data are the linear power, fuel rod geometry, thermal properties of fuel and cladding, primary system exit pressure, inlet mass flux for fuel channels and inlet coolant temperature.

In the calculation, the modeling of 1/8 fuel assembly of PWR-1000 was done using the COBRA-EN code as shown in Figure 1. Each fuel rod was modeled as one sub-channel. The analysis was done for the fuel center line and fuel surface temperatures of the sub-channel indicated by the maximum linear power of 7 kW/ft, 9 kW/ft, 11 kW/ft and 13kW/ft which equivalent to 22.96 kW/m, 29.53 kW/m, 36.09 kW/m and 42.65 kW/m established on sub-channel number of 41, 12, 3 and 2 in Figure 1 [5,14]. The chosen of maximum linear power was in compliance with analysis by NUREG [13]. This model was used in both calculations using fixed and temperature function of thermal conductivity. The sub-channel calculation result will provide the temperature distribution of the fuel meat, cladding and coolant, heat flux and DNBR

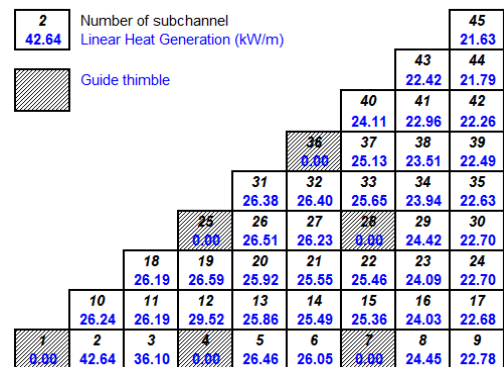


Figure 1. The 1/8 Fuel Assembly Calculation Model of COBRA-EN Code [5,13].

The second step was performing the calculations for thermal conductivity as temperature function using COBRA-EN code + MATPRO. The input data of thermal properties of fuel and cladding was given in negative value. So, the thermal property values of fuel and cladding as temperature functions will be calculated using Equations (1) to (4) by MATPRO subroutine, automatically. This calculation result was applied as reference in accepting the calculation result using fixed thermal conductivity. The analysis was accepted if deviation between temperature values using

Table 3. The Combination of The Thermal Conductivity of The Fuel and Cladding for PWR-1000 Sub-Channel Calculation Using COBRA-EN Code

		Thermal Conductivity of Zircaloy-4 cladding, $k_c$ (W/m.K)				
		13.00	15.57	16.76	17.94	18.69
Thermal Conductivity of fuel, $k_f$ (W/m.K)	$k_{xy}$	11	12	13	14	15
	5.28	21	22	23	24	25
	3.85	31	32	33	34	35
	3.60	41	42	43	44	45
	3.18	51	52	53	54	55
	2.90	61	62	63	64	65
	2.53	71	72	73	74	75
2.34						

fixed and temperature function of thermal conductivity was in the range of -10% to 10% [12] to avoid inaccuracy.

The third step was performing the calculation for the range values of thermal conductivity and heat capacity of fuel and cladding using the COBRA-EN code. The input data of thermal conductivity and heat capacity of fuel and cladding was given in proper value for each calculation. There were 35 combination of thermal conductivity of the fuel and cladding, as shown in Table 3.

The last step was comparing between the calculation result using thermal conductivity as temperature function and the calculation result using fixed thermal conductivity. The analysis was accepted if the deviation between both temperature was in the range of -10% to 10% [12].

### 3. RESULTS AND DISCUSSION

The calculation of the temperature for coolant and cladding, the fuel center line ( $T_{cm}$ ) and surface of the fuel meat ( $T_{om}$ ) at nominal power were performed by using 35 models of COBRA-EN code. The calculations results using COBRA-EN code for fixed thermal conductivity and COBRA-EN code + MATPRO for thermal conductivity as temperature function are shown in Table 4. The analysis was accepted if deviation between temperature values using fixed and temperature function of thermal conductivity was in the range of -10% to 10% [12] to avoid inaccuracy.

Table 4 shows the acceptance analysis of the fixed thermal conductivity of fuel and cladding compare to analysis using the ones as temperature function (MATPRO) for the hot sub-channel with a maximum linear power of 42.65kW/m. The table shows that the maximum fuel center line temperature using thermal conductivity as temperature function (MATPRO) for hot sub-channel was 1717.65°C and taken as the reference for calculation results deviation for the maximum fuel center line temperature of fixed thermal conductivity of 5.28 W/m.K (models of 11 to 15), 3.85 W/m.K (models of 21 to 25), 3.60 W/m.K (models of 31 to 35), 3.18 W/m.K (models of 41 to 45), 2.90 W/m.K (models of 51 to 55), 2.53 W/m.K (models of 61 to 65) and 2.34 W/m.K (models of 71 to 75).

The models of 11 to 15, models of 21 to 25 and models of 31 to 35 have maximum fuel center line temperature lower than the maximum fuel center line temperature of MATPRO and the temperature deviations were less than -10%. It means, the model of 11 to 15, models of 21 to 25 and models of 31 to 35 were not accepted for analysis.

While the models of 71 to 75 have have maximum fuel center line temperature higher than the maximum fuel center line temperature of MATPRO and the temperature deviations were more than 10%. It means, the model of 71 to 75 also were not accepted for analysis. Whereas, the model of 61 and 62 have deviation of fuel center line temperature in the range of -10 to 10%, but the average temperature deviation were more than 10%, so the model of 61 and 62 were not accepted for the analysis.

Table 4. The Acceptance Analysis of Fixed Thermal Conductivity of Fuel and Cladding for The Hot Sub-channel with a Maximum Linear Power of 42.65 kW/m

Model	Temperature (°C)								Acceptance
	average fuel		fuel centre line		fuel surface		inner clad		
	T-ave (°C)	Dev (%)	T-cm (°C)	Dev (%)	T-om (°C)	Dev (%)	T-ic (°C)	Dev (%)	
<b>MATPRO</b>	<b>1110.55</b>	<b>-</b>	<b>1717.65</b>	<b>-</b>	<b>569.05</b>	<b>-</b>	<b>403.45</b>	<b>-</b>	<b>Reference analysis</b>
11	898.15	-19.13	1187.15	-30.89	586.05	2.99	420.45	4.21	No
12	886.25	-20.20	1175.35	-31.57	574.25	0.91	408.65	1.29	No
13	882.05	-20.58	1171.15	-31.82	570.05	0.18	404.45	0.25	No
14	878.45	-20.90	1167.45	-32.03	566.35	-0.47	400.75	-0.67	No
15	876.35	-21.09	1165.35	-32.15	564.35	-0.83	398.75	-1.16	No
21	1014.05	-8.69	1410.45	-17.88	586.05	2.99	420.45	4.21	No
22	1002.15	-9.76	1398.65	-18.57	574.25	0.91	408.65	1.29	No
23	997.95	-10.14	1394.35	-18.82	570.05	0.18	404.45	0.25	No
24	994.35	-10.46	1390.75	-19.03	566.35	-0.47	400.75	-0.67	No
25	992.25	-10.65	1388.65	-19.15	564.35	-0.83	398.75	-1.16	No
31	1043.75	-6.02	1467.65	-14.55	586.05	2.99	420.45	4.21	No
32	1031.95	-7.08	1455.85	-15.27	574.25	0.91	408.65	1.29	No
33	1027.65	-7.46	1451.65	-15.49	570.05	0.18	404.45	0.25	No
34	1024.05	-7.79	1447.95	-15.70	566.35	-0.47	400.75	-0.67	No
35	1021.95	-7.98	1445.95	-15.82	564.35	-0.83	398.75	-1.16	No
41	1104.15	-0.58	1584.15	-7.77	586.05	2.99	420.45	4.21	Yes
42	1092.35	-1.64	1572.35	-8.46	574.25	0.91	408.65	1.29	Yes
43	1088.15	-2.02	1568.05	-8.71	570.05	0.18	404.45	0.25	Yes
44	1084.45	-2.35	1564.45	-8.92	566.35	-0.47	400.75	-0.67	Yes
45	1082.35	-2.54	1562.35	-9.04	564.35	-0.83	398.75	-1.16	Yes
51	1154.15	3.93	1680.45	-2.17	586.05	2.99	420.45	4.21	Yes
52	1142.35	2.86	1668.65	-2.85	574.25	0.91	408.65	1.29	Yes
53	1138.15	2.49	1664.45	-3.10	570.05	0.18	404.45	0.25	Yes
54	1134.45	2.15	1660.75	-3.31	566.35	-0.47	400.75	-0.67	Yes
55	1132.45	1.97	1658.75	-3.43	564.35	-0.83	398.75	-1.16	Yes
61	1237.25	11.41	1840.45	7.16	586.05	2.99	420.45	4.21	No
62	1225.45	10.35	1828.75	6.47	574.25	0.91	408.65	1.29	No
63	1221.25	9.97	1824.45	6.22	570.05	0.18	404.45	0.25	Yes
64	1217.55	9.63	1820.85	6.01	566.35	-0.47	400.75	-0.67	Yes
65	1215.45	9.45	1816.75	5.89	564.35	-0.83	398.75	-1.16	Yes
71	1290.25	16.17	1942.35	13.08	586.05	2.99	420.45	4.21	No
72	1278.35	15.11	1930.55	12.39	574.25	0.91	408.65	1.29	No
73	1274.05	14.72	1926.35	12.15	570.05	0.18	404.45	0.25	No
74	1270.45	14.40	1922.65	11.94	566.35	-0.47	400.75	-0.67	No
75	1268.35	14.21	1920.65	11.82	564.35	-0.83	398.75	-1.16	No

Consequently, in the results of the evaluation of thermal-hydraulics parameters [3], the maximum fuel center line temperature of AP1000 reactor should be corrected 15% higher.

Furthermore, the maximum fuel center line temperature using fixed thermal conductivity of models of 41 to 45, models of 51 to 55 and models of 63 to 65 have temperature deviations within -10% to 10% if compare to reference. The combinations of fixed fuel thermal conductivity in the range of

3.18 - 2.90 W/m.K and cladding thermal conductivity in the range of 13.00 - 18.69 W/m.K (models of 41 to 45 and models of 51 to 55) were accepted for analysis. And the combinations of fixed fuel thermal conductivity value of 2.53 W/m.K and cladding thermal conductivity in the range of 16.76 - 18.69 W/mK (models of 63 to 65) were also accepted for analysis.

## 4. CONCLUSION

The analysis of PWR-1000 sub-channel thermal-hydraulic using COBRA-EN code for finding the accurate fixed thermal conductivities value of fuel and cladding has been carried out, by comparing to the analysis one using thermal conductivity as temperature functions using COBRA-EN code + MATPRO. The analysis using fixed thermal conductivity was accepted, if the deviation of the temperature was in the range of -10% to 10 %. Hence, the analysis was accurate, if the calculation using combination of the fixed fuel thermal conductivity in the range of 3.18 - 2.90 W/m.K and cladding thermal conductivity variation of 13.00 - 18.69 W/m.K, and the calculation using combination of the fuel thermal conductivity of 2.53 W/m.K and cladding thermal conductivity variation of 16.76 - 18.69 W/m.K.

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