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Steady State Temperature Distribution Calculation in BN-350 Reactor Fuel Rod

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Abstract

The steady state temperature distribution in one dimension for BN-350 reactor fuel rod has been calculated via solving heat conduction equation numerically.

The calculations covers the case of constant and variable heat transfer coefficient considering different heat flux and inlet reactor core temperature.

The obtained results at average heat flux and core inlet temperature have been compared with reported results, it is found that these results could be a good references for reactor designing and for reactor safety processes when compared with higher values of material melting points.

Keywords :- Temperature Distribution, BN-350 reactor.

Introduction

As the first step in establishing the fuel and cladding temperature patterns in the operating reactor core consideration will be given to the steady state axial temperature distribution along fuel rod resulting from the coolant flowing. Normally, fuel rods are cooled by the flow of coolant through a number of parallel channels which transverse the entire reactor core [1].

In our present work we study temperature distribution in the fuel and clad which concerned with the removal of heat generated in fuel for the Russian power reactor BN-350 which starts working since 1973 with electrical power 350 Mew and composed of two enriched zones with UO_2PuO_2 fuel , and blanket contains depleted Uranium with coolant sodium for average heat flux 142.05 w/cm^2 and average coolant temperature 400 C^o , there are 211 assemblies with 169 rods of fuel (ss-316 clad) in each of them and there are 12 control rods [2,3] .

We solved time dependent heat conduction equation including heat source and tried to solve it for slab, cylindrical and spherical geometry using finite difference techniques [2,4].

Heat Transfer Coefficient

Heat transfer to liquid metal coolants is strikingly different from the transfer of heat to ordinary fluids, largely because the thermal conductivity of liquid metals are so much higher than those of other types of coolants. One important effect of the high conductivity of liquid metals is that even when they are flowing under turbulent conditions, these coolants absorb heat mostly by conduction.

Since energy is transferred from the fuel rods by conduction and convection, where in conduction heat is transferred to the surface of the rod by transmitting from one location in it to another as a result of a temperature difference (there is no macroscopic movement of any portion of the rod), but in convection, there is a transfer of heat to a moving liquid as a result of temperature difference, thus the heat conduction to the surface of a fuel rod is carried into the coolant and out of the fuel rod by convection .The temperature distribution within a coolant channel containing a liquid metal resembles the temperature distribution in a solid conductor whose axis and circumference are held at different temperatures. The temperature varies more slowly across the channel with a liquid metal than with a nonmetallic coolant [1,11].

For the case of a liquid metal flowing under turbulent conditions through a hexagonal lattice of rods, parallel to it, it was found that [9]:

$$Nu = 24.15 \log [-8.12 + 12.76 (s/d) - 3.65 (s/d)^2] + 0.0174 [1 - \exp \{- 6 (s/d-1)\}](Pe - 200)^{0.9} \quad \ldots\ldots\ (5)$$

For $1.1 \le (s/d) \le 1.5$ and $200 \le Pe \le 2000$

where: Nu is Nusselt number, S/d is Lattice pitch to rod diameter ratio , and Pe is Peclet number. This correlation agrees well with most of the experimental data over the ranges of S/d and Pe indicated, which were used to calculate heat transfer Coefficient [4] from the flowing relation : $H= Nu.K/ De$ where De is the equivalent diameter.

Fuel Rod Temperature Distribution

Energy is transferred from the fuel rods by convection to the coolant flows between the pins in the assembly geometry[1]. The heat flux from the cladding to coolant is given by [11]:

$$q = H(T_{co} - T_b) = \chi/2\pi R_{co} \quad \ldots\ldots\ldots\ldots\ (6)$$

Where:

C_o : outer cladding temperature in (C^o) with a radius R_{oc} (mm) and χ is linear power w/m which is convected away according to the following expression[6]:

$$2\pi R_{co}\ H\ (T_{co}-T_b)\ dr = \chi dr = mC_p dT_b \quad \ldots\ldots\ldots\ldots\ldots\ (7)$$

where (m) is the coolant flow rate, so the average coolant temperature rise T_b across an assembly is directly proportional to linear power and inversely to mass flow rate, but we have for a channel of length L [1] :

$$\chi(r)=\chi_o \sin \pi r/L \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where χ_o is the maximum linear power at the center of the channel, therefore substituting Eq.(8) into Eq.(7) and integrating over (r) we get:

$$T_b=\chi_o L/(mC_p\pi)[1-\mathrm{Cos}(\pi r/L)] \ldots\ldots\ldots (9)$$

Which is used for heat transfer coefficient calculations and for average bulk temperature [5] .

Results and Discussion

The temperature distribution as a function of r for a fuel rod has been calculated using Eq.(4) and Eq.(9), where the obtained results are tabulated in table (1) and shown graphically in fig(1). The maximum temperature value 667.34 C° will be at the center of fuel rod because of the high fission in this region and reduced at the surface to reach 405.07 C° (which is cosine type). The values of heat transfer coefficients for different values of coolant velocities and bulk temperature are listed in table (2) where it is seen from Fig.(2) that temperature of fuel rod center reduced exponentially with velocity of coolant until it reaches 734.09 C° for 1000 cm/sec (which is the best and the less temperature of the clad at this velocity) where heat transfer coefficient at this moment is 11.17 x 10^4 (w/m^2.C°) which is no so far from the reference value (11.72 x10^4) (w/m^2.C°) of refs.[2,3] .

Table (1) : Temperature distribution in one dimension for fuel rod, Tb =400 C° , V = 800 m /sec.

r (Cm)	H (W/m^2. C°) x 10^4	T (C°)
0·000	1.3934336	667.34
0.043	1.3942712	660.22
0.0866	2.9325748	638.98
0.13	4.4352891	602.96
0.173	7.1078512	554.39
0.216	10.553752	492.52
0.26	16.646674	419.57
0.2601	16.665934	419.51
0.275	19.983713	414.48
0.29	24.577271	409.66
0.305	31.335084	405.07

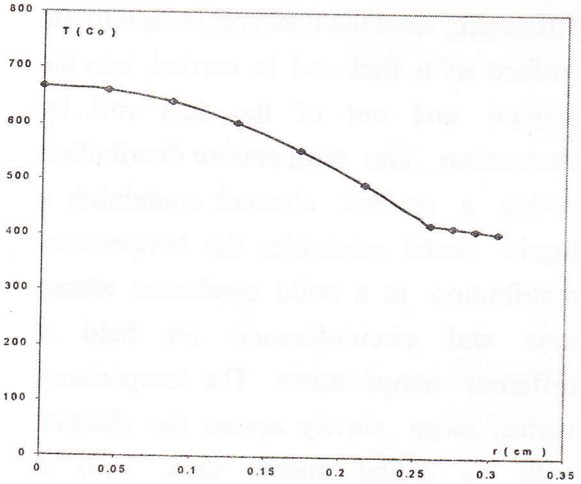

Fig.(1) : Temperature distribution in one dimension for fuel rod , Tb = 400C0 , V= 800m/s .

Table(2): Temperature distribution in the hot point for fuel rod as afunction of velocity of the coolant, T_b=400 C°.

V (Cm/ sec)	H (W/m². C°) x 10^4	T_m (C°)
200	3.084701	879.49
400	5.371071	823.88
600	7.429061	756.19
800	9.3515765	740.41
1000	11.179256	734.09

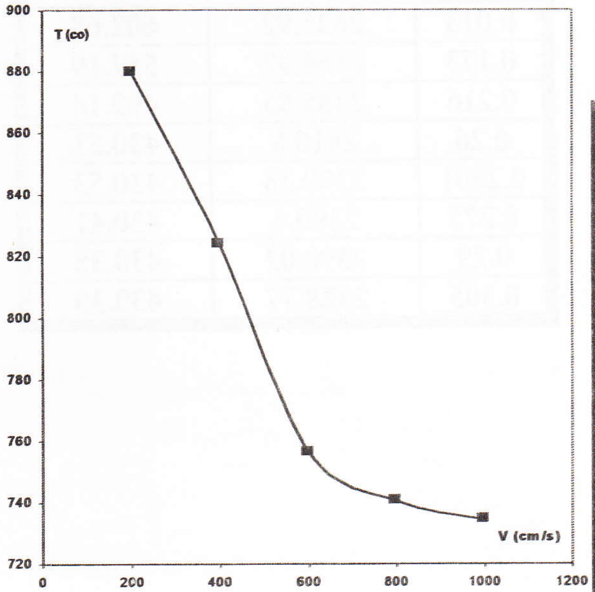

Fig.(2): Temperature distribution in the hot point of fuel rod as a function of coolant velocity .

The obtained results for temperature values as a function of distance for stopping coolant case where control rods are up, were tabulated in table (3) for Q_{max} =547.49 w/cm³ [or 130.76 Cal/cm³.s] graphically shown in Fig.(3) where it is shown that after 2 sec of operating point , the temperature of the center of fuel rod and its surface is 698 C° and 448 C° respectively, and after 150 sec of working it will be 2876C° and 2523 C°, this fact indicates that temperature changing is small and almost stays at steady state from distance (0.05 cm) to the surface.

Table (3): Temperature distributionin one Dimension, Tb=400Co, V=0 and control roads up.

r(cm)	T(c°)	
	After 150 sec	After 2 sec
0	2876.19	698.9
0.043	2436.18	691.77
0.0866	2441.15	607.38
0.013	2435.2	634.06
0.173	2460.91	585.03
0.216	2471.31	522.51
0.26	2440.52	448.68
0.2601	2460.9	448.68
0.275	2488.96	448.55
0.29	2515.20	448.49
0.305	2523.35	448.49

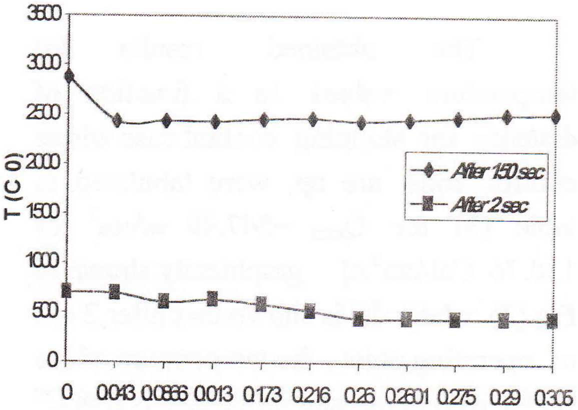

Fig (3) Temperature distribution along x-axis for cylindrical fuel rod, inlet temp. =400 c , control rods up

The other case, when control rods are down, temperature distribution was measured as recorded in table (4) and represented graphically in Fig.(4) where the temperature varies from 662 C^o to 430 C^o (from the center to the surface) after 2 sec of reactor operating and varies from 2705 C^o to 2388 C^o after 150 sec of working where H = 0 and for $Q_{max} = 781.629\ w/cm^3$ [or 186.68 $Cal/Cm^3.s$], this is because of high fission processes in the center of the fuel rod and because of the existence of control rods down reactor core .We show from this graph that the temperature at a distance from 0 (cm) to 0.14 cm may be at steady state case and after this distance there is reducing in it because of the high speed of the coolant.

Table (4): Temperature istributionin one dimension, Tb=400Co, V=0and control roads down.

r(cm)	T(c^o)	
	After 150 sec	After 2 sec
0	2705.53	662.86
0.043	2696.79	656.21
0.0866	2670.63	663.37
0.013	2625.92	602.68
0.173	2564.92	557.19
0.216	2485.85	499.14
0.26	2410.8	430.53
0.2601	2390.38	430.53
0.275	2390.4	430.41
0.29	2390.03	430.35
0.305	2388.77	430.35

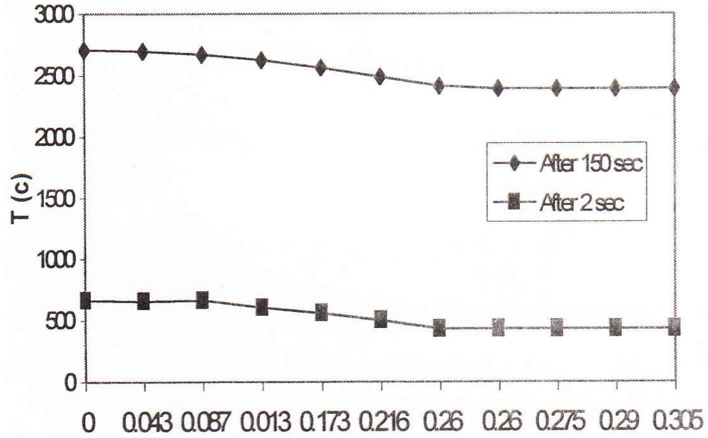

Fig. (4) Temperature distribution along x-axis for cyilndrical fuel rod, inlet temp. =400 C0, control rods down

Conclusions

This research is useful for the condition of losing coolant accident to know the better properties of coolant which is so important for designing reactor core , assemblies of fuel rods , its height , out diameter and the pitch . The computer programming, which was designed for this research, could be used to study transient condition and developed to calculate these states in other power reactors.

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