

JAERI 1145

A Preliminary Study
of Reactor Thermal Characteristics
(Heavy Water Moderated
Carbon Dioxide Cooled Reactor)

September 1967

日本原子力研究所

Japan Atomic Energy Research Institute

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A Preliminary Study of Reactor Thermal Characteristics (Heavy Water Moderated Carbon Dioxide Cooled Reactor)

Abstract

A preliminary study of the reactor thermal characteristics of the heavy water moderated carbon dioxide cooled reactor was made and the following conclusions or results were obtained.

- a) Over 60 kg/cm² of the coolant pressure will be considered for the plain surface of the fuel,
- b) the coolant temperature rise through the core would be taken over about 250°C considering the blower power required,
- c) some study of the properly designed core shape from the standpoint of the thermal characteristics was made and the range of the thermal design parameters to be considered were obtained.

June 1967

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重水減速炭酸ガス冷却炉の炉心熱特性サーベイ

要　　旨

重水減速炭酸ガス冷却炉の炉心熱特性を明らかにするため、種々の調査研究をおこない、おおよそ次の諸点を明らかにした。

- (a) 平滑な被覆管燃料の場合、冷却材圧力は約 60 kg/cm² 以上が考慮される。
- (b) 送風機動力の観点から、冷却材炉内温度上昇は約 250°C 以上必要である。
- (c) 設計された炉心型状の妥当性の検討や考慮の対象となる設計パラメータの範囲が確かめられた。

1967 年 6 月

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1. Introduction

In September, 1964, the heavy water moderated power reactor (boiling light water cooled and carbon dioxide cooled types) was selected by the national power reactor development program committee, as the reactor for further development in Japan. Following this decision, Japan Atomic Energy Research Institute has made a study on the problems of the development of the above reactors and also a preliminary survey of the reactor characteristics quantitatively.

The survey of the heavy water moderated carbon dioxide cooled on the thermal design was made in order to make clear the following points:

- (A) effect of the coolant temperature rise through the core on the reactor thermal characteristics,
- (B) effect of the coolant pressure on the reactor thermal characteristics,
- (C) proper range of the input design parameters for designing the above reactor in the next design stage.

2. Equations used for study

Equations used for this survey work are listed below.

2.1 Pressure drop through core (ΔP)

The pressure drop through the core can be expressed by the following equation.

$$\Delta P = \Delta P_1 + \Delta P_2 + \Delta P_3 \quad (1)$$

where

$$\Delta P_1: \text{friction loss} = \int_0^{H_0} (4f) \left(\frac{G_0^2}{2g} \right) \left(\frac{1}{\gamma} \right) \frac{dH}{De}$$

$$f = 0.046 Re^{-0.2}$$

G_0 =mass velocity of the coolant

γ =coolant specific weight

De =hydraulic diameter

H_0 =core height

$$\Delta P_2: \text{pressure drop at the gap between fuel elements} = \sum \beta_1 \cdot \left(\frac{G_0^2}{2g} \right) \left(\frac{1}{\gamma} \right)$$

β_1 =correction factor determined experimentally, and in this case 0.5 is adopted.

$$\Delta P_3: \text{acceleration loss} = \left(\frac{G_0}{g} \right) (V_{o2} - V_0) = \frac{G_0^2}{g} \left(\frac{1}{\gamma_0} \right) \left[\frac{T_{o2}}{T_0} \cdot \frac{P_0}{P_{o2}} - 1 \right]$$

V_0 =coolant velocity at reactor inlet

V_{o2} =coolant velocity at reactor outlet

T_0 =coolant temperature at reactor inlet

T_{o2} =coolant temperature at reactor outlet

P_0 =coolant pressure at reactor inlet

P_{o2} =coolant pressure at reactor outlet

γ_0 =coolant specific weight at reactor inlet

2.2 Blower Power (B.P.)

This may be obtained as

$$\begin{aligned} \text{B.P.} &= \left(\frac{\kappa}{\kappa-1} \right) \cdot \left(\frac{P_0}{\gamma_0} \right) \cdot \left[1 - \left(\frac{P_0 - \Delta P - \Delta P'}{P_0} \right)^{\frac{\kappa-1}{\kappa}} \right] \cdot (G_t) \left(\frac{1}{\eta_m} \cdot \frac{1}{\eta_c} \right) \\ &\doteq \left(\frac{P_0}{\gamma_0} \right) \cdot \left[\frac{\Delta P + \Delta P'}{P_0} + \frac{1}{2\kappa} \left(\frac{\Delta P + \Delta P'}{P_0} \right)^2 \right] \cdot (G_t) \cdot \left(\frac{1}{\eta_m} \cdot \frac{1}{\eta_c} \right) \end{aligned} \quad (2)$$

where

$\Delta P'$ =coolant pressure drop outside the reactor

G_t =total coolant flow rate

η_m =blower efficiency

η_c =motor efficiency

P_0 =coolant pressure at reactor inlet

γ_0 =coolant specific weight at reactor inlet

κ =ratio of specific heats of coolant at constant pressure, to constant volume

2.3 Film Temperature Drop at Hot Spot (Δt)

The film temperature drop at the hot spot, Δt , will be written in the following form.

$$\Delta t = (\varphi) \cdot \left(4\pi \int \overline{k d \theta} \right) \cdot (\phi_a) \cdot (\phi_r) \cdot (\phi_l) \cdot (\phi_E) / (\alpha) \cdot (\pi \cdot D_f) \quad (3)$$

where

φ =correction factor (hot spot may not be at the highest heat flux)

$$\int \overline{k d \theta} = \text{mean } \int k d \theta$$

ϕ_a =axial power peaking factor

ϕ_r =radial power peaking factor

ϕ_l =local power peaking factor

ϕ_E =engineering safety factor

D_f =outside diameter of fuel rod

α =heat transfer coefficient

2.4 Coolant Temperature Rise through Core (ΔT)

The coolant temperature rise in the hot channel is expressed as

$$\Delta T = \left(4\pi \int \overline{k d \theta} \right) (\phi_r) (H_0) / \left(\frac{G_0 \cdot S}{N_f} \right) (C_p) \quad (4)$$

where

G_0 =mass velocity of the coolant

N_f =number of fuel rods per channel

S =coolant flow area in channel

C_p =specific heat of the coolant

H_0 =core height

2.5 Heat Transfer Equation

$$\text{Nu} = 0.023 \text{ Re}^{0.8} \text{ Pr}^{0.4} \quad (5)$$

where

Re =Reynolds number

Pr =Prandtl number

Nu =Nusselt number

In this study, the following approximations were made.

- (a) Total thermal power to the coolant is 1,500 MWt,
- (b) one third of the thermal power given to the coolant by the blower is converted into the electric power,
- (c) the heat exchangers whose thermal characteristics is the same as of the EL-4, is considered in the study,
- (e) the physical constants of carbon dioxide was surveyed (JAERI-memo 2149) (1) and, the data of GA-1038 (2) were mainly used,
- (d) maximum allowable temperature of the cladding surface is 650°C.

3. Study results

The flow charts of the following calculations are shown in Fig. 1 (A) to (C).

3.1 Effect of coolant pressure and temperature rise through core on reactor characteristics

These problems were studied, using the fuel geometry of the design by the First Atomic Power Industry Group (Fig. 2), and the study results are shown in Fig. 3 to Fig. 5. From these figures, the following conclusions may be drawn.

- (a) The coolant pressure would be over 60 kg/cm² for the plain surface of the fuel, and for the rough surface this would be changed as in the AGR.
- (b) More than about 250°C of the coolant temperature rise through the core is considered.
- (c) Increase in the thermal efficiency by increasing the coolant pressure can be seen in Fig. 5, when the coolant temperature rise through the core is kept constant, 250°C. In this

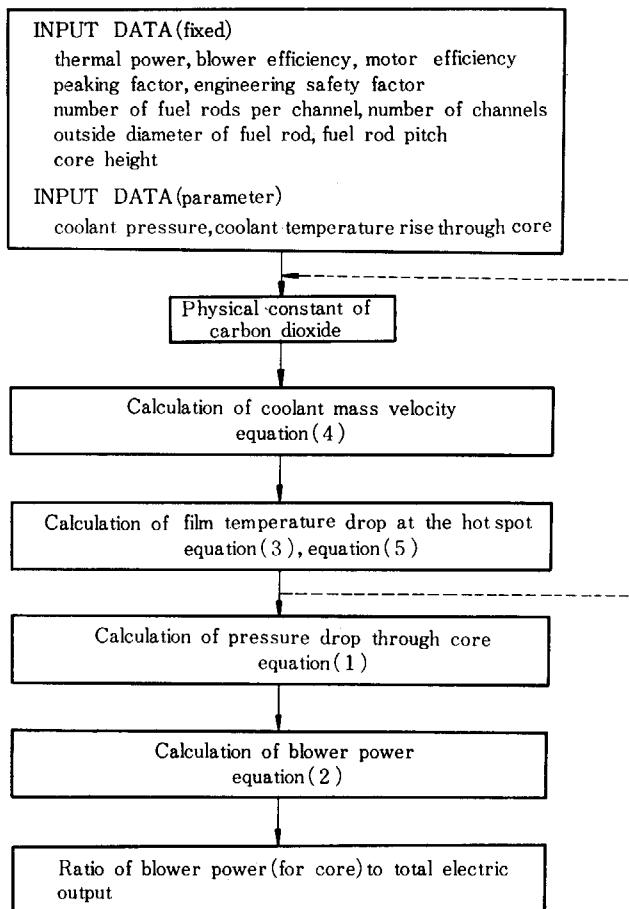
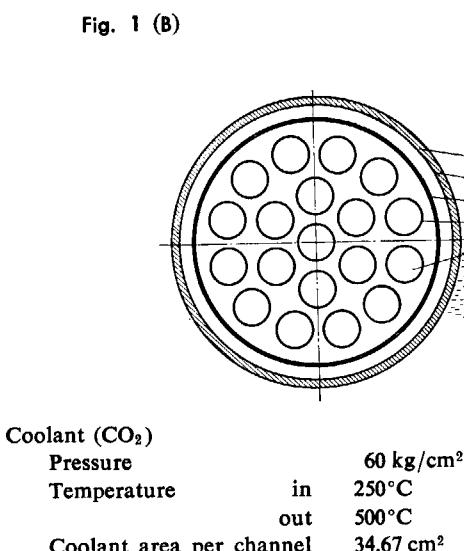
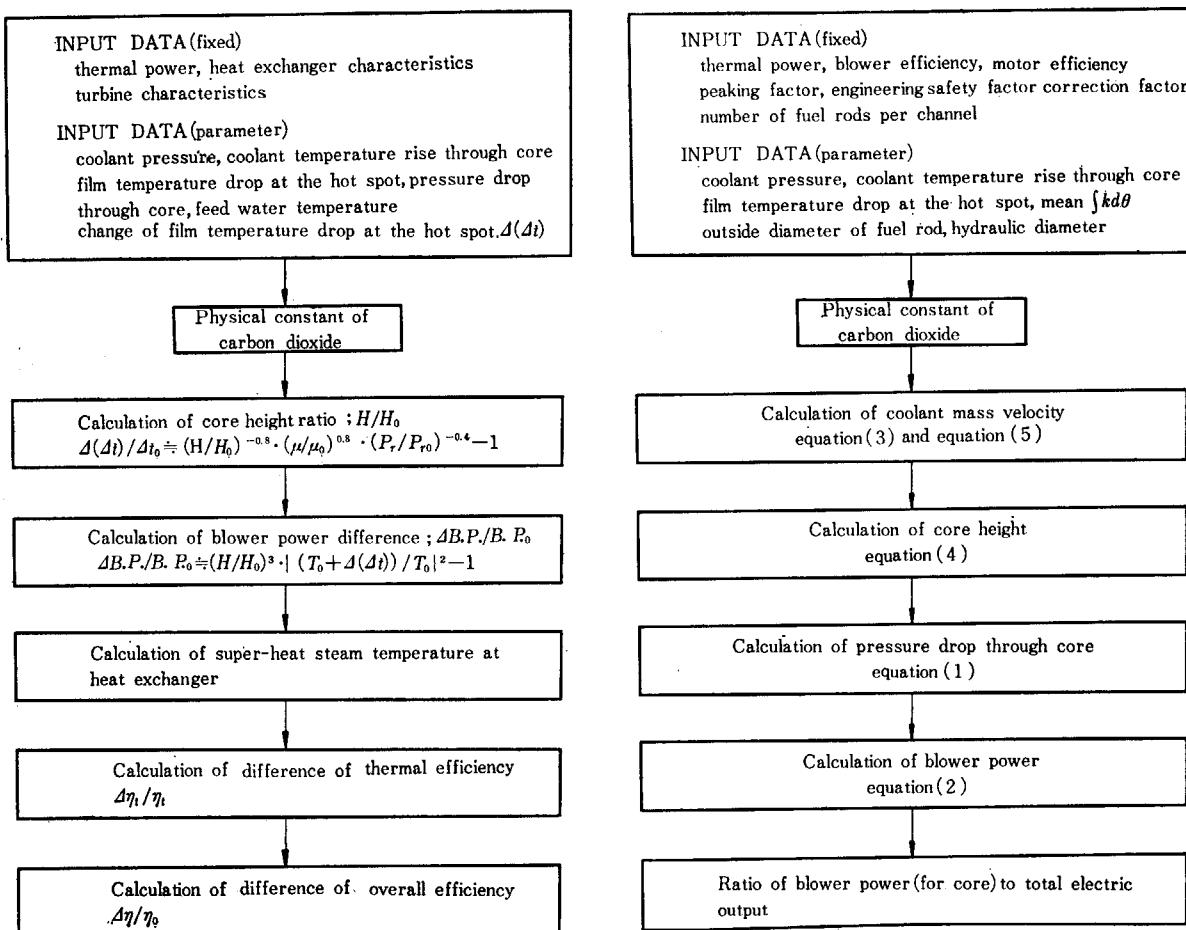


Fig. 1(A) Flow Chart of Calculation.



	Material	Diameter (mm)		Thickness	Density gr/c.c.
		I.D.	O.D.		
Fuel pellet	UO_2 (1.2% max.)	—	14	—	10.33
Fuel cladding	Stainless steel 20% Cr, 25% Ni Nb stab'd	14	14.6	0.3	7.98
Liner	Zry 30 0.5% Cu, 0.5% Mo	92	94	1	6.53
Thermal insulator	Zry 30 (foil), CO_2	94	104	0.75, 4.25	—
Pressure tube	Zry 2 1.5% Sn, 0.12% Fe 0.1% Cr, 0.05% Ni	104	110	3	6.55

(Listed values of dimensions and densities are those used for the nuclear calculation.)
Square lattice pitch 228 mm

Fig. 2 Lattice designed by FAPIG

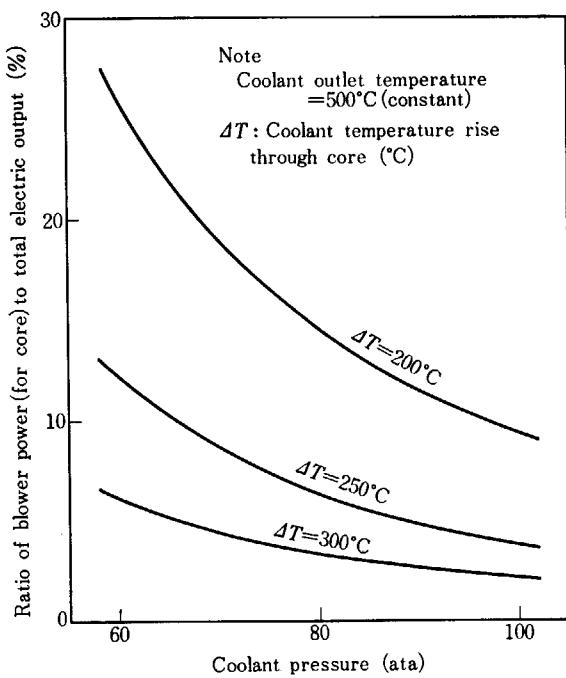


Fig. 3 Effect of coolant pressure and coolant temperature rise through core on blower power.

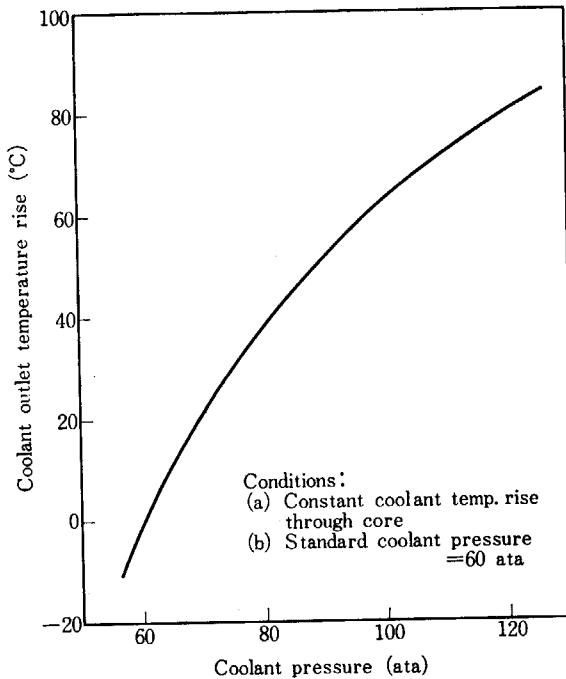


Fig. 4 Effect of coolant pressure on coolant outlet temperature rise.

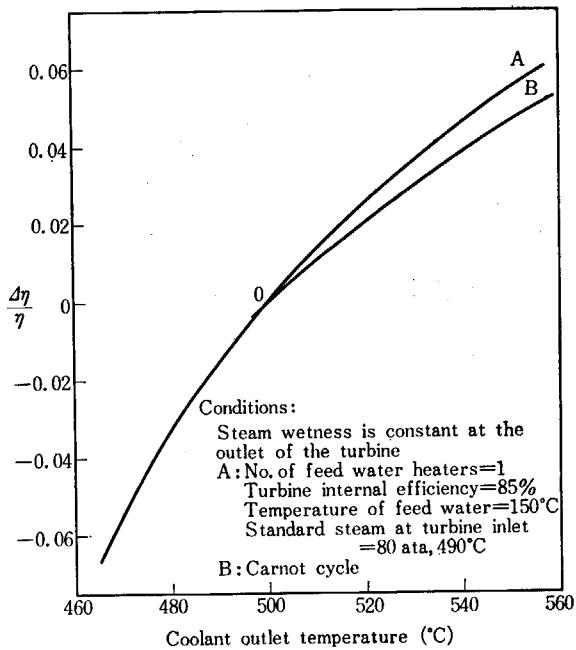


Fig. 5 Effect of coolant outlet temperature on thermal Efficiency.

case, disadvantages, caused by increasing the coolant pressure ... piping difficulty, increasing the thickness of the pressure tube in the core, etc. . . . should be taken into consideration.

3.2 Check of core shape

In the heavy water moderated carbon dioxide cooled reactor, the following points may greatly affect the reactor thermal characteristics:

- (a) film temperature drop at the hot spot, Δt ,

- (b) coolant temperature rise through the core, ΔT ,
- (c) coolant pressure drop through the core, ΔP ,
- (d) coolant pressure at the reactor inlet, P_0 .

There may arise the question whether the designed reactor with the particular values of Δt , ΔT , ΔP and P_0 will be the most favorable one, or which is better to make the core flat or slender when the same geometry of the fuel is employed. This problem was investigated under the following conditions and assumptions, and the results are given in Fig. 6 (A) to (G),

- (a) the same assumptions or conditions as written in 2.4,
- (b) number of feed water heater is one.

All curves in Fig. 6 (A) to (G) are normalized and therefore the designed points with four particular parameters (Δt , ΔT , ΔP and P_0) shown in the figures are always origin ($H/H_0=1.0$, $\Delta\eta/\eta=0$).

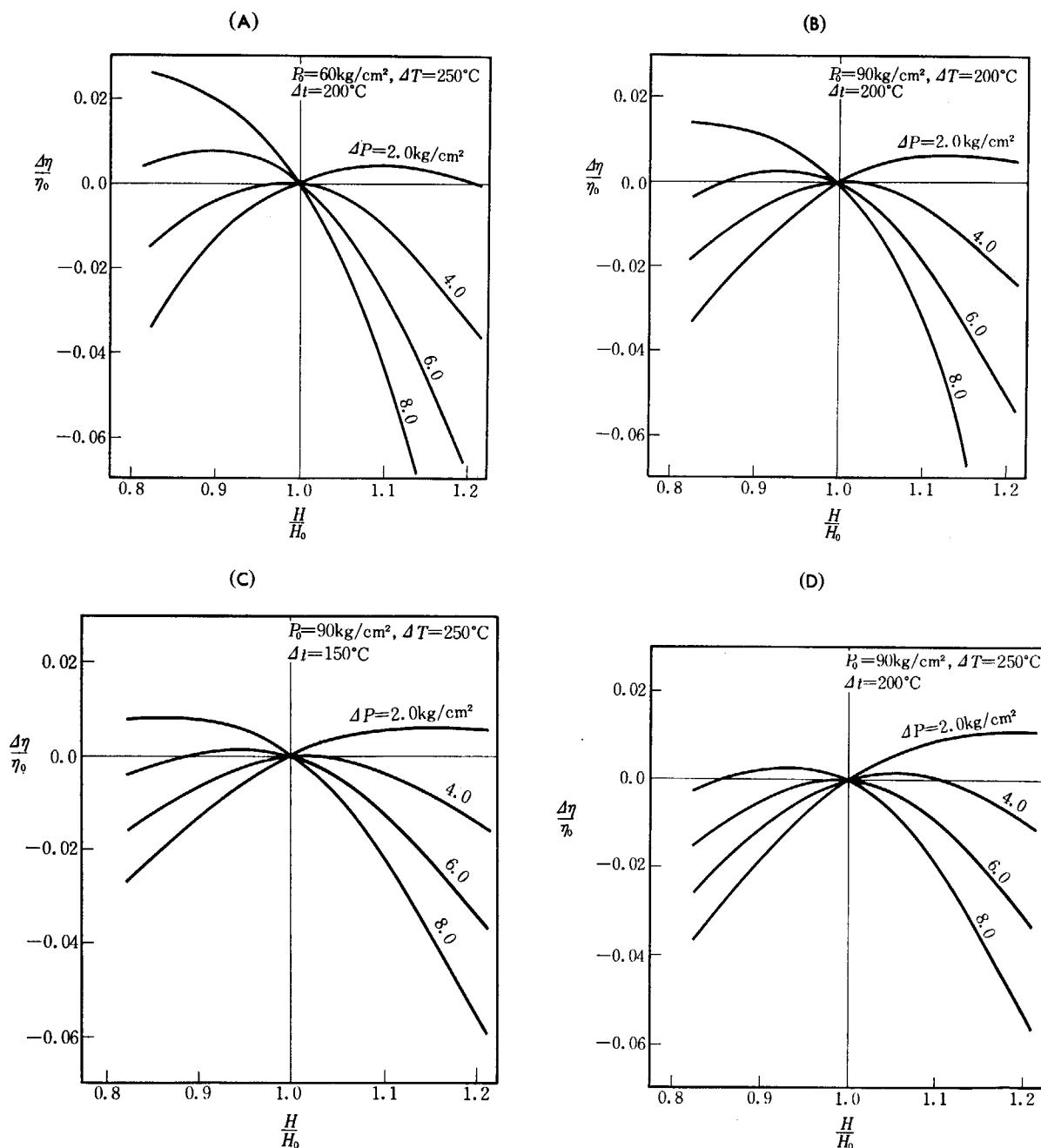
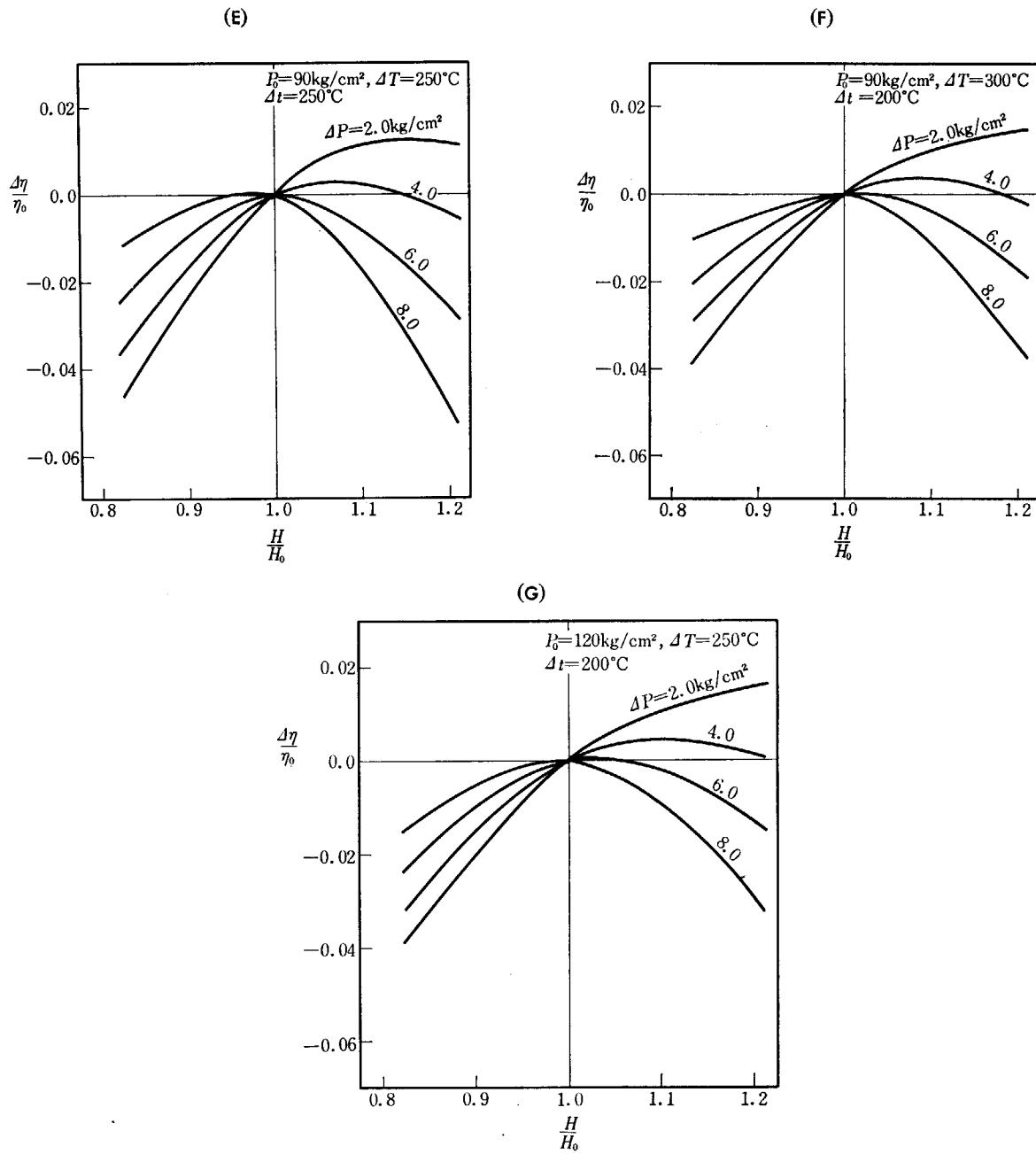


Fig. 6 Optimization study in reactor shape with particular designed fuel



If the maximum point of the curve (which shows a thermal characteristics of the designed reactor with the particular values of Δt , ΔT , ΔP and P_0) is on the right hand side of 1.0 of H/H_0 , the reactor should then be designed as a slender one. On the other hand, when the maximum point is on the left hand side, it would be better to make the reactor flat. In such cases, there still exists the possibility of modifying the fuel geometry.

For example, the reactor designed by FAPIG has the following specific values: 60 kg/cm² of the coolant pressure at the reactor inlet, about 200°C of the film temperature drop at the hot spot, 250°C of the coolant temperature rise through the core, and about 5.5 kg/cm² of the coolant pressure drop through the core. From Fig. 6 (A), the maximum point is on the left side on the FAPIG's design, it may be better to make it little more flat. In the EL-4 (3), the reactor was designed for the stainless steel cladding core in the following: 60 kg/cm² of the coolant pressure at the reactor inlet, 250°C of the colant temperature rise through the core, about 200°C of the film temperature drop at the hot spot, and about 4 kg/cm² of the coolant pressure drop through the core. It might be said that the designed reactor be reasonable from the Fig. 6 (A).

The maximum points of these curves are influenced by the coolant pressure, as seen in Fig. 6 (A) to (G). The higher the coolant pressure, the larger the coolant pressure drop through the core would be permitted.

3.3 Proper input Range

In the above equations, (1), (3), (4) and (5), there are the following variables, if ϕ_a , ϕ_r , ϕ_i , ϕ_E , φ and N_f are given.

ΔP : pressure drop through core

Δt : film temperature drop at hot spot

ΔT : coolant temperature rise through core

G_0 : mass velocity of the coolant

$\int \overline{k d \theta}$: mean $\int k d \theta$

H_0 : core height

De : hydraulic diameter

D_f : outside diameter of fuel rod

S : coolant flow area

δ : gap between fuel rods

γ : coolant specific weight

α : heat transfer coefficient

Among these variables, heat transfer coefficient, α , can be calculated by the equation (5), and the coolant specific weight, γ , hydraulic diameter, De , and coolant flow area, S , may be expressed as

$$\alpha = F_1(P_0, G_0, H, De, S, \int \overline{k d \theta}) \quad (6)$$

$$De = F_2(D_f, \delta, N_f) \quad (7)$$

$$S = F_3(D_f, \delta, N_f) \quad (8)$$

On the other hand, the number of independent equations is three, and the core height, H_0 , coolant mass flow rate, G_0 , and gap between fuel rods, δ , will be determined with the specified values of five other variables, ΔP , D_f , ΔT , Δt and $\int \overline{k d \theta}$ (these variables give a large influence upon the reactor thermal characteristics). In other words, if P_0 , ΔP , D_f , Δt , ΔT and $\int \overline{k d \theta}$ are given, the reactor core dimensions or characteristics will be determined.

In large reactors, power peaking factors, ϕ_a , ϕ_r , ϕ_i , and engineering safety factors, ϕ_E , may be little changed by its shape (within a reasonable range); and the following values were taken in this investigation.

$$\phi_a = 1.39$$

$$\phi_r = 1.23$$

$$\phi_i = 1.05$$

$$\phi_E = 1.30 \text{ (including ambiguity of the heat transfer coefficient)}$$

Also the coolant temperature at the reactor outlet was kept constant at 500°C for convenience of the calculation and the number of fuel rods in one cluster was fixed at 19. Total thermal output of the core is assumed 1,500 MWt.

The calculation results are shown in Fig. 7 (A) to (I) and TABLE 1 (A) to (I). It might be reasonable that the core height is in the range of 3.5 m to 6.5 m for the large reactor, taking into account nuclear considerations and pressure tube manufacturing. At the same time, a blower power (for the reactor core only) of less than about 10% of the electrical power output may be adopted, considering the plant efficiency. The above considerations may give the proper input range of the

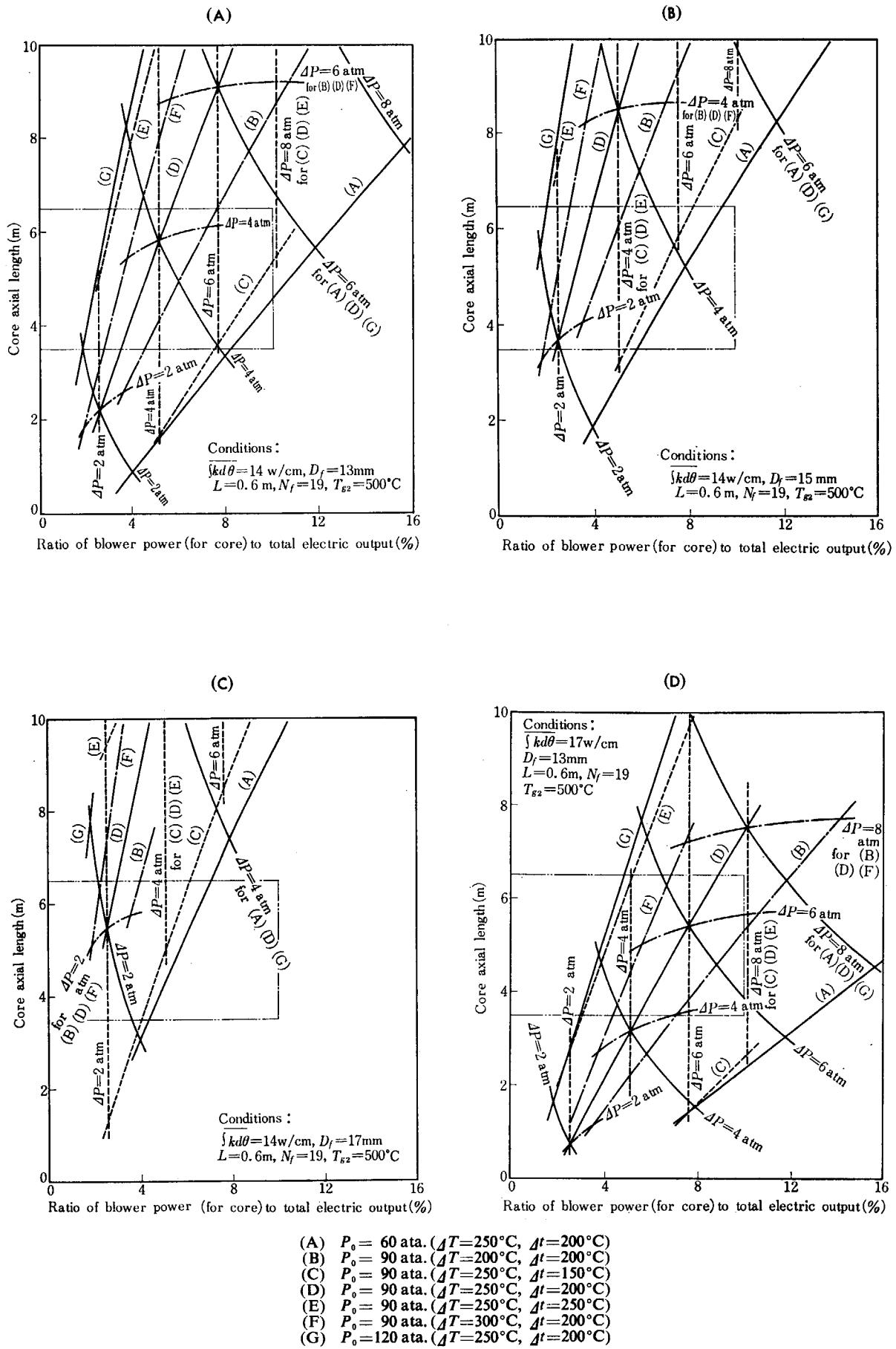
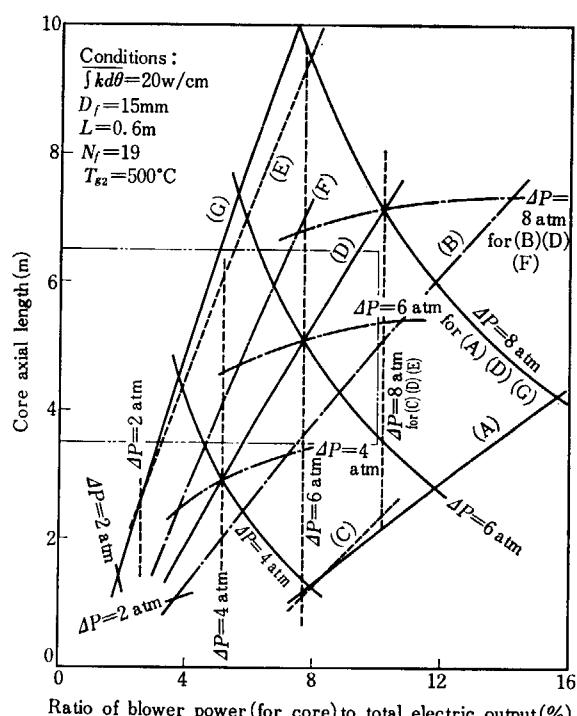
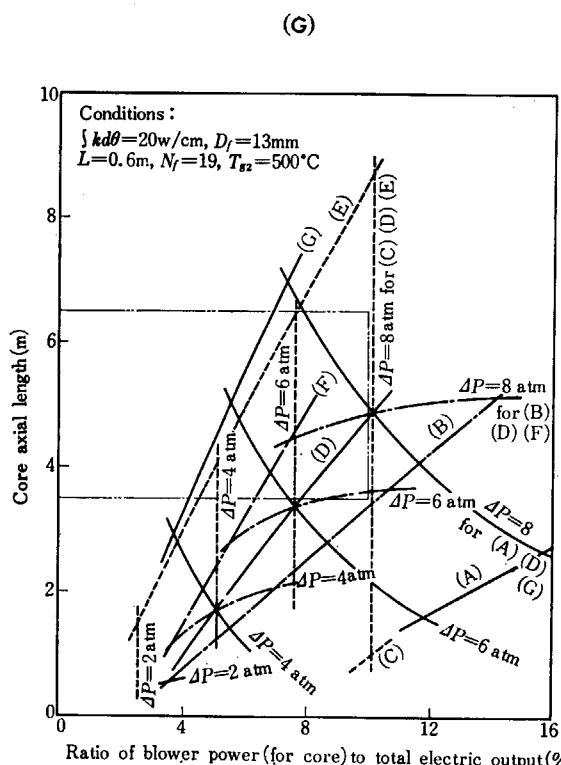
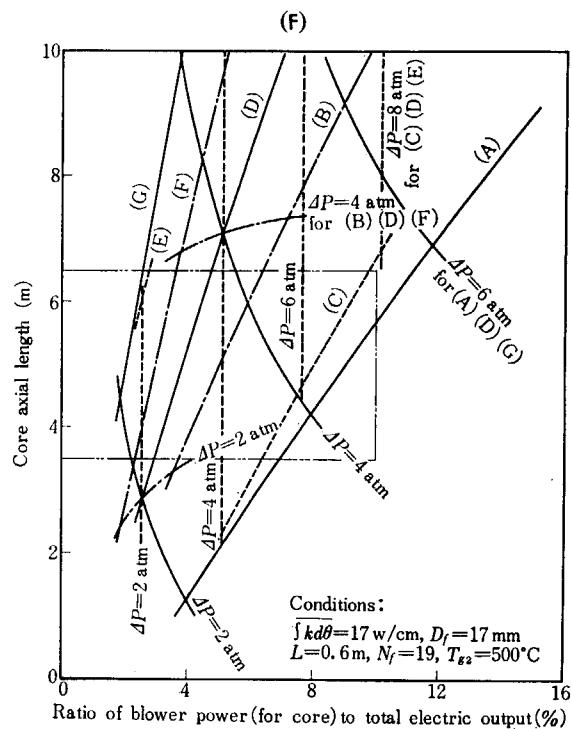
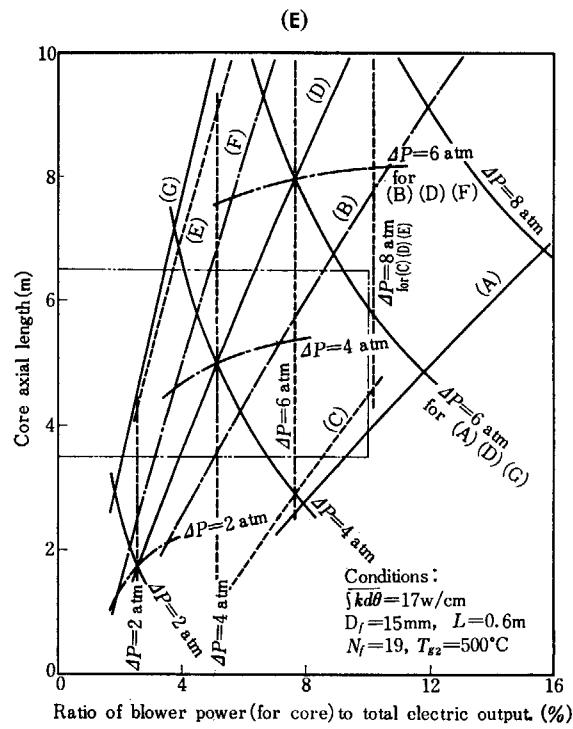


Fig. 7 Relation between core height and blower power (for core) with thermal parameters.



- (A) $P_0 = 60 \text{ atm}$, $(\Delta T = 250^\circ\text{C}, \Delta t = 200^\circ\text{C})$
 (B) $P_0 = 90 \text{ atm}$, $(\Delta T = 200^\circ\text{C}, \Delta t = 200^\circ\text{C})$
 (C) $P_0 = 90 \text{ atm}$, $(\Delta T = 250^\circ\text{C}, \Delta t = 150^\circ\text{C})$
 (D) $P_0 = 90 \text{ atm}$, $(\Delta T = 250^\circ\text{C}, \Delta t = 200^\circ\text{C})$
 (E) $P_0 = 90 \text{ atm}$, $(\Delta T = 250^\circ\text{C}, \Delta t = 250^\circ\text{C})$
 (F) $P_0 = 90 \text{ atm}$, $(\Delta T = 300^\circ\text{C}, \Delta t = 200^\circ\text{C})$
 (G) $P_0 = 120 \text{ atm}$, $(\Delta T = 250^\circ\text{C}, \Delta t = 200^\circ\text{C})$

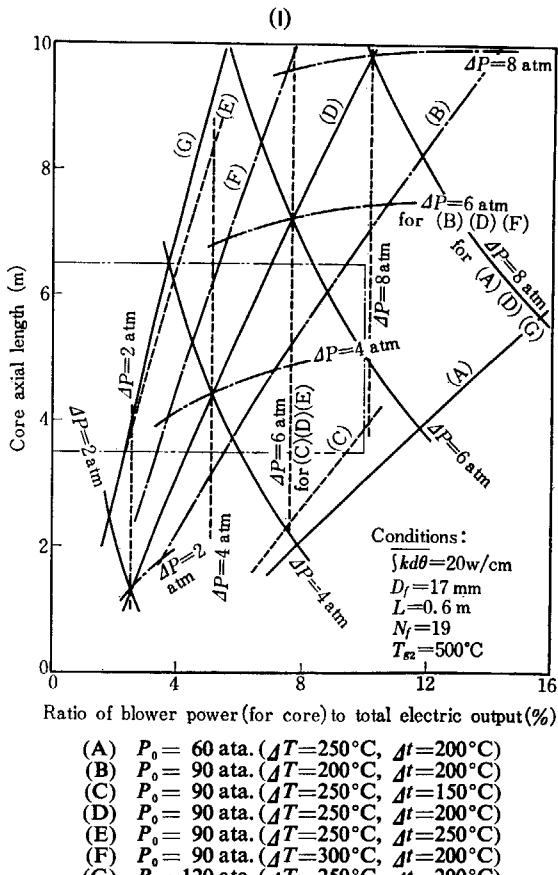


TABLE 1. (A)
Relation between reactor dimensions and thermal parameters.

Conditions: $\int k d\theta = 14 \text{ w/cm}$, $D_f = 13 \text{ mm}$, $L = 0.6 \text{ m}$, $N_f = 19$, $T_{in} = 500^\circ\text{C}$

P_0 (ata)	ΔT ($^\circ\text{C}$)	Δt ($^\circ\text{C}$)	ΔP (atm)	δ (mm)	D (mm)	H_0 (m)	G_0 ($\text{kg/m}^2\text{s}$)
60	250	200	2	0.35	65.3	0.86	1500
			4	2.62	78.6	3.33	2065
			6	4.19	87.8	5.66	2315
			8	5.43	94.9	7.83	2475
90	200	200	2	2.57	78.3	2.58	1980
			4	5.36	94.5	6.09	2370
			6	7.20	105.7	9.18	2580
		250	2	—	—	—	—
			4	0.69	67.3	1.67	2285
			6	1.96	74.7	3.62	2740
			8	2.96	80.6	5.47	2995
			2	1.69	71.3	2.20	1855
			4	4.27	88.3	5.83	2290
			6	6.04	98.6	9.10	2510
			8	7.43	105.7	12.11	2660
		300	2	4.70	90.8	4.97	1775
			4	8.05	110.3	10.29	2060
			6	—	—	—	—
			8	—	—	—	—
120	250	200	2	0.98	69.0	1.77	1720
			4	3.38	83.0	5.42	2215
			6	5.07	92.9	8.83	2450
			8	6.39	100.5	11.97	2610
			2	2.74	79.3	3.54	2025
			4	5.59	96.0	8.26	2415
			6	7.53	107.3	12.42	2625
			8	—	—	—	—

L : length of cluster

D : liner tube inner diameter

TABLE 1. (B)

Conditions: $\int k d\theta = 14 \text{ w/cm}$, $D_f = 15 \text{ mm}$, $L = 0.6 \text{ m}$, $N_f = 19$, $T_{g2} = 500^\circ\text{C}$

P_0 (ata)	ΔT (°C)	Δt (°C)	ΔP (atm)	δ (mm)	D (mm)	H_0 (m)	G_o (kg/m²s)
60	250	200	2	1.31	80.6	1.86	1520
			4	3.99	96.3	5.23	1915
			6	5.84	107.2	8.27	2105
			8	7.30	115.7	11.12	2235
90	200	200	2	3.95	96.1	4.08	1835
			4	7.23	115.3	8.66	2145
			6				
			8				
	250	150	2				
			4	1.69	82.7	3.24	2240
			6	3.18	91.6	5.87	2560
			8	4.32	98.6	8.36	2760
	200	200	2	2.90	90.0	3.72	1750
			4	5.94	107.8	8.53	2085
			6	8.05	120.1	12.78	2265
			8				
	300	200	2	6.54	111.3	7.30	1615
			4				
			6				
			8				
120	250	200	2	2.05	84.8	3.27	1665
			4	4.93	101.8	8.24	2035
			6	6.89	113.3	12.66	2220
			8	8.44	122.5	16.76	2350

 L : length of cluster D : liner tube inner diameter

TABLE 1. (C)

Conditions: $\int k d\theta = 14 \text{ w/cm}$, $D_f = 17 \text{ mm}$, $L = 0.6 \text{ m}$, $N_f = 19$, $T_{g2} = 500^\circ\text{C}$

P_0 (ata)	ΔT (°C)	Δt (°C)	ΔP (atm)	δ (mm)	D (mm)	H_0 (m)	G_o (kg/m²s)
60	250	200	2	2.37	96.6	3.06	1460
			4	5.48	114.8	7.40	1770
			6	7.62	127.3	11.26	1930
			8				
90	200	200	2	5.40	114.4	5.76	1695
			4				
			6				
			8				
	250	150	2	0.18	83.8	1.29	1515
			4	2.75	98.8	5.08	2130
			6	4.51	109.1	8.50	2380
			8	5.88	117.1	11.64	2540
	200	200	2	4.19	107.2	5.46	1630
			4	7.72	128.0	11.54	1905
			6				
			8				
	300	200	2	8.42	132.0	9.83	1480
			4				
			6				
			8				
120	250	200	2	5.67	115.9	7.82	1730
			4				
			6				
			8				

 L : length of cluster D : liner tube inner diameter

TABLE 1. (D)

Conditions: $\int k d\theta = 17 \text{ w/cm}$, $D_f = 13 \text{ mm}$, $L = 0.6 \text{ m}$, $N_f = 19$, $T_{o2} = 500^\circ\text{C}$

P_0 (ata)	ΔT (°C)	Δt (°C)	ΔP (atm)	δ (mm)	D (mm)	H_0 (m)	G_0 (kg/m²s)
60	250	200	2	—	—	—	—
			4	0.99	69.0	1.52	2180
			6	2.28	76.5	3.04	2555
			8	3.34	82.8	4.54	2785
90	200	200	2	0.94	68.7	1.16	2080
			4	3.30	82.5	3.54	2670
			6	4.91	91.9	5.70	2950
			8	6.18	99.4	7.72	3140
	250	150	2	—	—	—	—
			4	—	—	—	—
			6	0.43	65.7	1.41	2750
			8	1.31	70.8	2.67	3220
		200	2	0.17	64.2	0.75	1780
			4	2.36	77.0	3.16	2535
			6	3.86	85.9	5.42	2845
			8	5.05	92.7	7.53	3045
		250	2	2.70	79.0	2.75	1975
			4	5.54	95.5	6.42	2360
			6	7.48	107.0	9.70	2570
			8	—	—	—	—
	300	200	2	—	—	—	—
			4	1.61	72.7	2.71	2400
			6	3.02	80.9	5.00	2745
			8	4.13	87.5	7.19	2965
120	250	200	2	1.08	69.6	1.63	2140
			4	3.47	83.6	4.82	2725
			6	5.13	93.2	7.73	3010
			8	6.43	100.9	10.45	3200

 L : length of cluster D : liner tube inner diameter

TABLE 1. (E)

Conditions: $\int k d\theta = 17 \text{ w/cm}$, $D_f = 15 \text{ mm}$, $L = 0.6 \text{ m}$, $N_f = 19$, $T_{o2} = 500^\circ\text{C}$

P_0 (ata)	ΔT (°C)	Δt (°C)	ΔP (atm)	δ (mm)	D (mm)	H_0 (m)	G_0 (kg/m²s)
60	250	200	2	—	—	—	—
			4	2.02	84.7	2.75	2100
			6	3.58	93.9	4.86	2375
			8	4.81	101.1	6.82	2555
90	200	200	2	1.98	84.5	2.13	2010
			4	4.76	100.9	5.33	2450
			6	6.67	112.0	8.17	2675
			8	8.17	120.8	10.77	2830
	250	150	2	—	—	—	—
			4	0.07	73.0	1.08	2130
			6	1.37	81.0	2.90	2755
			8	2.36	86.7	4.60	3060
		200	2	1.11	79.3	1.74	1855
			4	3.66	94.3	5.00	2350
			6	5.44	104.8	7.98	2595
			8	6.83	113.0	10.74	2755
		250	2	4.08	96.9	4.28	1825
			4	7.45	116.5	9.12	2135
			6	—	—	—	—
			8	—	—	—	—
	300	200	2	0.34	74.9	1.22	1645
			4	2.78	89.3	4.59	2265
			6	4.45	99.1	7.66	2525
			8	5.78	106.8	10.56	2700
120	250	200	2	2.15	85.4	2.94	2060
			4	4.98	102.1	7.20	2495
			6	6.93	113.5	11.01	2725
			8	8.47	122.6	14.53	2880

 L : length of cluster D : liner tube inner diameter

TABLE 1. (F)

Conditions: $\int \bar{k} d\theta = 17 \text{ w/cm}$, $D_f = 17 \text{ mm}$, $L = 0.6 \text{ m}$, $N_f = 19$, $T_{g2} = 500^\circ\text{C}$

P_0 (ata)	ΔT (°C)	Δt (°C)	ΔP (atm)	δ (mm)	D (mm)	H_0 (m)	G_o (kg/m²s)
60	250	200	2	0.52	85.7	1.24	1480
			4	3.16	101.2	4.22	1980
			6	4.97	111.8	6.92	2200
			8	6.40	120.2	9.42	2345
90	200	200	2	3.12	101.0	3.30	1900
			4	6.32	119.8	7.34	2250
			6	8.52	132.7	10.85	2435
			8				
	250	150	2				
			4	0.92	88.0	2.31	2230
			6	2.38	96.7	4.66	2635
			8	3.53	103.5	6.84	2865
		200	2	2.09	95.0	2.89	1790
			4	5.05	112.3	7.10	2175
			6	7.12	124.5	10.88	2375
			8	8.76	134.0	14.38	2515
		250	2	5.61	115.6	6.09	1690
			4				
			6				
			8				
	300	200	2	1.26	90.0	2.40	1675
			4	4.07	106.5	6.79	2115
			6	6.00	117.8	10.69	2330
			8	7.52	126.7	14.32	2470
120	250	200	2	3.31	102.0	4.49	1940
			4	6.59	121.3	9.92	2295
			6	8.87	134.7	14.74	2485
			8				

L: length of cluster*D*: liner tube inner diameter

TABLE 1. (G)

Conditions: $\int \bar{k} d\theta = 20 \text{ w/cm}$, $D_f = 13 \text{ mm}$, $L = 0.6 \text{ m}$, $N_f = 19$, $T_{g2} = 500^\circ\text{C}$

P_0 (ata)	ΔT (°C)	Δt (°C)	ΔP (atm)	δ (mm)	D (mm)	H_0 (m)	G_o (kg/m²s)
60	250	200	2	—	—	—	—
			4	—	—	—	—
			6	0.92	68.8	1.60	2590
			8	1.86	74.2	2.65	2950
90	200	200	2	0.10	63.7	0.55	2050
			4	1.88	74.3	2.10	2880
			6	3.30	82.6	3.65	3260
			8	4.42	89.2	5.12	3500
	250	150	2	—	—	—	—
			4	—	—	—	—
			6	—	—	—	—
			8	0.13	64.0	1.00	3060
		200	2	—	—	—	—
			4	0.97	69.1	1.70	2580
			6	2.36	77.1	3.38	3080
			8	3.40	83.2	4.87	3370
		250	2	1.33	71.1	1.50	2020
			4	3.78	85.5	4.10	2620
			6	5.45	95.2	6.45	2890
			8	6.76	103.0	8.75	3065
	300	200	2	—	—	—	—
			4	0.38	65.5	1.19	2360
			6	1.60	72.7	2.81	2950
			8	2.60	78.5	4.42	3265
120	250	200	2	—	—	—	—
			4	2.04	75.4	2.95	2920
			6	3.52	84.0	5.05	3340
			8	4.65	90.5	6.98	3585

L: length of cluster*D*: liner tube inner diameter

TABLE 1. (H)

Conditions: $\int k d \theta = 20 \text{ w/cm}$, $D_f = 15 \text{ mm}$, $L = 0.6 \text{ m}$, $N_f = 19$, $T_{\sigma 2} = 500^\circ\text{C}$

P_0 (ata)	ΔT (°C)	Δt (°C)	ΔP (atm)	δ (mm)	D (mm)	H_0 (m)	G_o (kg/m²s)
60	250	200	2	—	—	—	—
			4	0.60	76.5	1.26	2125
			6	1.97	84.5	2.82	2560
			8	3.03	90.8	4.24	2805
90	200	200	2	0.54	76.1	0.98	2020
			4	3.02	90.6	3.32	2690
			6	4.67	100.3	5.40	2985
			8	5.95	107.8	7.34	3180
	250	150	2	—	—	—	—
			4	—	—	—	—
			6	0.01	73.1	1.08	2575
			8	0.96	78.5	2.37	3180
		200	2	—	—	—	—
			4	2.03	84.9	2.92	2540
			6	3.60	94.1	5.11	2870
			8	4.82	101.2	7.15	3080
		250	2	2.37	87.0	2.56	1985
			4	5.30	104.2	6.11	2390
			6	7.33	115.9	9.32	2605
			8	—	—	—	—
	300	200	2	—	—	—	—
			4	1.28	80.3	2.45	2385
			6	2.72	88.8	4.69	2760
			8	3.85	95.6	6.78	2990
120	250	200	2	0.68	77.0	1.41	2095
			4	3.20	91.7	4.53	2745
			6	4.92	101.7	7.36	3045
			8	6.21	109.6	9.96	3240

 L : length of cluster D : liner tube inner diameter

TABLE 1. (I)

Conditions: $\int k d \theta = 20 \text{ w/cm}$, $D_f = 17 \text{ mm}$, $L = 0.6 \text{ m}$, $N_f = 19$, $T_{\sigma 2} = 500^\circ\text{C}$

P_0 (ata)	ΔT (°C)	Δt (°C)	ΔP (atm)	δ (mm)	D (mm)	H_0 (m)	G_o (kg/m²s)
60	250	200	2	—	—	—	—
			4	1.24	90.0	2.01	3610
			6	2.80	99.1	3.90	4200
			8	4.04	106.3	5.69	4560
90	200	200	2	1.50	91.5	1.82	3580
			4	4.93	111.6	4.81	4600
			6	6.20	119.0	7.46	4875
			8	7.74	128.0	9.93	5170
	250	150	2	—	—	—	—
			4	—	—	—	—
			6	0.89	87.8	2.36	2720
			8	1.90	93.8	3.99	3085
		200	2	0.55	86.0	1.33	1795
			4	3.17	101.3	4.44	2390
			6	4.97	111.8	7.24	2655
			8	6.38	120.1	9.84	2830
		250	2	3.61	103.9	3.85	1865
			4	6.98	123.6	8.36	2190
			6	—	—	—	—
			8	—	—	—	—
	300	200	2	—	—	—	—
			4	2.30	96.2	4.01	2290
			6	3.98	106.0	6.90	2580
			8	5.29	113.7	9.56	2765
120	250	200	2	1.65	92.4	2.51	2065
			4	4.50	109.0	6.50	2550
			6	6.46	120.6	10.07	2795
			8	8.05	129.8	13.45	2965

 L : length of cluster D : liner tube inner diameter

reactor core dimensions and core thermal design, which will be seen in Fig. 7 (A) to (I) (area enclosed by the dotted lines).

It is noticed that increasing the coolant pressure and the film temperature drop at the hot spot greatly influence the reactor thermal characteristics. The latter, however, means lowering the thermal efficiency of the plant, as the temperature of the coolant at the reactor outlet must be lowered considering the allowable temperature of the cladding.

4. Conclusion

A preliminary investigation on the reactor thermal characteristics of the heavy water moderated carbon dioxide cooled reactor was made, and many experiments on the thermal and hydrodynamics of this type of reactor should be necessary for further detailed next design.

Acknowledgement

The authors would like to express their gratitude to Mr. Y. OKAMOTO (M.S.) for his helpful suggestion on this work.

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