

THERMAL EFFICIENCIES AND OTEC POTENTIALS AT SOME OFF-SHORE SITES ALONG THE INDIAN COAST*

V. RAMESH BABU, P. V. SATHE AND V. V. R. VARADACHARI
National Institute of Oceanography, Dona Paula, Goa - 403 004

ABSTRACT

The annual variation of thermal efficiency of closed OTEC power cycle at some selected off-shore sites along the Indian coast is presented. OTEC potentials at these sites have been evaluated in order to identify promising locations for exploration of OTEC power. It is shown that priority could be given to three locations for setting up experimental plants — the first one off Lakshadweep Islands, the second off Great Nicobar Island and the third off Krishnapatnani on the central east coast.

Key-words : Thermal energy, Indian Coast, OTEC plant.

INTRODUCTION

The concept of Ocean Thermal Energy Conversion (OTEC), first proposed by Jacques d'Arsonval, a French Scientist, 100 years ago is the conversion of heat stored in the ocean into electricity using warm surface waters to evaporate a working fluid whose vapour is later fed to a tubogenerator and cold waters ($\approx 5^{\circ}\text{C}$) pumped from about 1000 m depth to condense the vapour in order to complete the cycle (Fig. 1). OTEC is now being re-examined as an alternative energy source to the fast depleting conventional sources. The production cost of power from the OTEC plant is mainly determined by the plant capital cost since the operational and maintenance costs are small. Huge equipment is necessary to handle large amount of water and ammonia flow since the temperature difference (ΔT) involved is only of the order of 20°C . However, recent results of the experimental OTEC plant off Hawaii islands have indicated that OTEC power would be viable on commercial basis in the next 10-15 years. OTEC power has acquired importance in view of its renewability and pollution free production. The rate of OTEC power production is largely dependent on the thermal efficiency which in turn depends on ΔT . By the turn of this century, India requires about 100 million tonnes of crude oil and 162,000 MW of electric power (Ramachandran and Gururaja, 1977) as compared to the present requirement of about 30 million tonnes of crude oil and 35,000 MW power. Since two-third of India's oil requirement is met by import, the increase in the consumption of oil leads to a great economic burden. Among the alternative and renewable energy sources, OTEC seems to be important for India since the seas around trap great amount of solar

* Paper presented at the 'National Workshop on Energy from the Sea' held at the National Institute of Oceanography, Goa on 15 and 16 December, 1980.

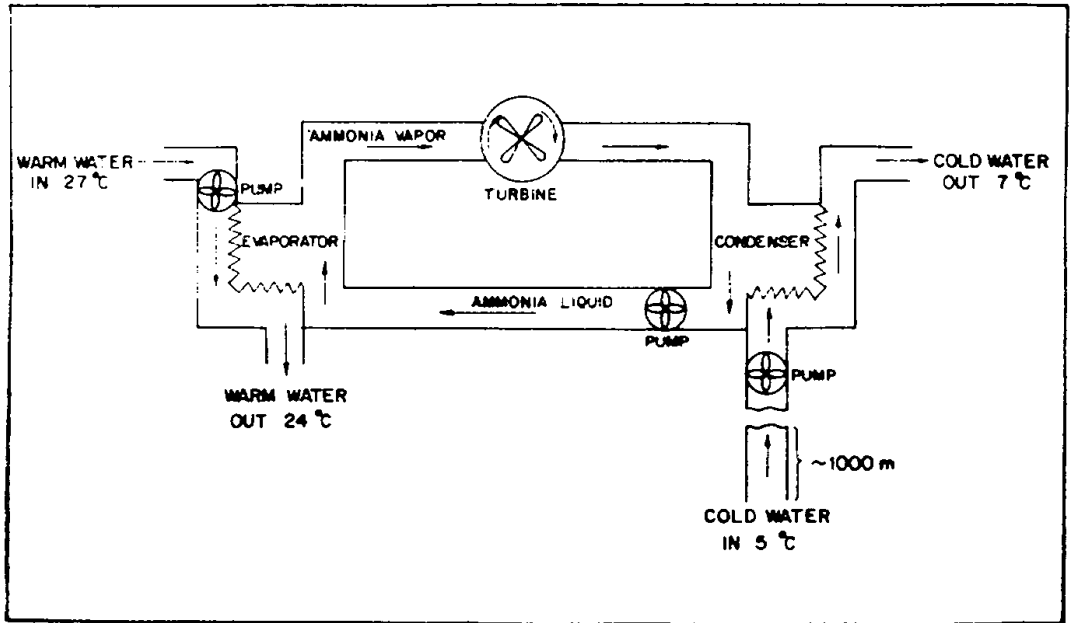


Fig. 1. Schematic diagram of OTEC closed power cycle.

energy being in tropical region. Exploitation and utilisation of this energy source must be pursued immediately.

Fig. 2 shows locations of some selected sites to evaluate OTEC potential for the Indian coastal states and also for the Andaman, Nicobar and Lakshadweep Islands. These sites have been selected mainly on the consideration of their proximity to the 1000 m isobath. An adequate thermal gradient ($\approx 20^\circ\text{C}/1000\text{ m}$), equivalent to a larger thermal efficiency in conversion, should be available round the year at any potential OTEC site. In the present paper, thermal efficiencies at various sites along the Indian coast have been computed and their seasonal variations are discussed.

DATA AND METHODS

During each cycle of the OTEC system, an amount of thermal energy Q_1 from the warm waters is absorbed to evaporate the working fluid. Out of this, an amount of Q_2 is given back to the cold waters pumped from 1000 m. Thus the remaining heat ($Q_1 - Q_2$) represents the output of the system and is utilised for the production of electricity. The thermal efficiency E of any heat engine is the ratio of its output to input expressed as

$$E = (Q_1 - Q_2) / Q_1 = (T_1 - T_2) / T_1 = (\Delta T) / T_1$$

where T_1 and T_2 are the absolute temperatures of the source and sink.

However, for optimum heat transfer within the heat exchangers, temperature differences $T_1 - T_m$ and $T_m - T_2$ should be as large as possible. T_m and T_m are maximum and minimum temperatures experienced by a working fluid such as ammonia. Normally these temperature differences would be of the order of one-fourth of ΔT (Dunn, 1977).

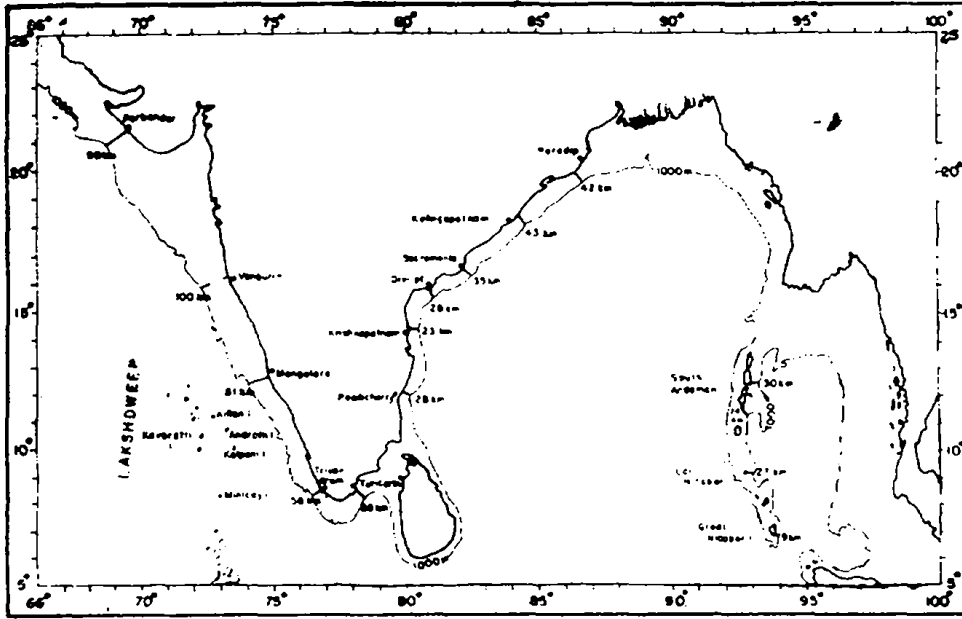


Fig. 2. Locations of some off-shore sites selected for the evaluation of OTEC potentials.

Data on mean monthly sea surface temperature (T_1) and temperature at 1000 m depth (T_2) have been obtained from Koninklijk Netherland Meteorologische Institut (1952) and Wyrki (1971) respectively. The seasonal variation of the thermal efficiency at the site, the knowledge of which is a pre-requisite for setting up an OTEC plant, is mainly controlled by that of sea surface temperature since seasonal variations in temperature at 1000 m depth are quite negligible.

RESULTS AND DISCUSSION

Seasonal variation of sea surface temperature (SST)

Table I presents monthly SST variation at the selected sites. Except in the north off Porbander and Paradip, SST in general varies seasonally with two maxima, one in early summer and the other in Autumn, and two minima corresponding to winter and late summer. The annual range of SST gradually decreases from 6.5°C at Porbander to 2.2°C at Trivandrum along the west coast and from 5.0°C at Paradip to 2.0°C at Tuticorin along the east coast. The annual range is small ($\approx 2.0^\circ\text{C}$) around the Islands. The distributions of the mean minimum SST and its range of annual variation for the Bay of Bengal region are plotted in Fig. 3. The lowest surface temperatures ($< 24^\circ\text{C}$) in the region are encountered during winter near the head of the Bay which has also the maximum annual range ($> 5^\circ\text{C}$). The surface waters in the south Andaman Sea undergo least annual variation ($\sim 2.0^\circ\text{C}$) which indicates that this area (particularly off the east coast of Nicobar Islands) has great potential for installation of OTEC plants, from the point of view of temperature distribution.

Table I. Annual variation of mean monthly SST ($^{\circ}$ C).

State	Locations (off)	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
W. Bengal & Orissa	Paradip	24.5	25.0	27.0	28.0	29.0	29.5	28.0	28.0	28.0	28.0	27.0	24.5
Orissa & A.P.	Kalingapatnam	25.2	25.5	27.0	28.3	29.0	29.0	28.0	28.0	28.4	28.5	27.3	25.4
Andhra Pradesh	Sacramento	25.4	26.2	27.3	28.4	29.0	29.0	28.0	28.0	28.3	28.5	27.2	25.5
	Divi Point	25.5	26.2	27.5	28.5	29.0	29.0	28.0	28.0	28.2	28.5	27.2	25.5
T.N. & Pondicherry	Krishnapatnam	25.7	26.4	27.8	28.6	29.0	29.0	28.0	28.0	28.1	28.3	27.2	25.7
Tamil Nadu	Merakanam	25.8	26.5	27.9	28.9	29.0	28.5	28.0	27.5	27.9	28.0	27.0	26.0
Kerala	Tuticorin	27.0	28.0	29.0	28.8	27.3	26.5	26.2	27.0	27.2	27.4	27.0	27.0
	Irivandrum	27.0	27.0	27.0	28.2	29.2	29.0	27.0	27.0	26.0	27.0	27.0	27.0
Karnataka	Mangalore	27.0	27.0	28.0	29.1	29.0	27.3	27.1	26.0	27.0	27.0	27.8	27.0
Goa & Maharashtra	Vengurla	26.5	26.0	27.0	28.0	28.8	28.5	27.2	26.9	27.0	27.0	27.5	26.9
Gujarat	Porbandar	23.0	22.5	24.2	26.2	28.0	29.0	28.0	27.0	27.0	27.0	26.0	24.2
Islands	Andaman & Nicobar Is.	27.2	27.2	28.2	29.0	29.0	28.0	28.0	28.0	28.0	28.0	28.0	27.5
	Lakshadweep Is.	27.0	27.0	28.0	29.0	29.0	28.0	27.1	26.8	27.0	27.0	28.5	27.0

Table II. Annual variation of mean temperature difference ($^{\circ}$ C) between surface and 1000m depth.

Locations (off)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1. Paradip	18.0	18.5	20.5	21.3	22.5	23.0	21.5	21.5	21.5	21.5	20.5	18.0	20.7
2. Kalingapatnam	18.7	19.0	20.5	21.8	22.5	22.5	21.5	21.5	21.9	22.0	20.8	18.9	21.0
3. Sacramento	18.9	19.7	20.8	21.9	22.5	22.5	21.5	21.5	21.8	22.0	20.7	19.0	21.1
4. Divi Point	19.0	19.7	21.0	22.0	22.5	22.5	21.5	21.5	21.7	22.0	20.7	19.0	21.1
5. Krishnapatnam	19.2	19.9	21.3	22.1	22.5	22.5	21.5	21.5	21.6	21.8	20.7	19.2	21.2
6. Pondicherry	19.3	20.0	21.4	22.4	22.5	22.0	21.5	21.0	21.4	21.5	20.5	19.5	21.1
7. Tuticorin	20.2	20.2	21.2	22.2	22.5	20.5	19.7	19.4	20.2	20.4	20.6	20.2	20.6
8. Irivandrum	20.1	20.1	20.1	21.3	22.3	22.1	20.1	20.1	19.1	20.1	20.1	20.1	20.5
9. Mangalore	19.4	19.4	20.4	21.5	21.5	19.7	19.5	18.4	19.4	19.4	20.2	19.4	19.9
10. Vengurla	18.5	18.0	19.0	20.0	20.8	20.5	19.2	18.9	19.0	19.0	19.9	18.9	19.3
11. Porbandar	14.5	14.0	15.7	17.7	19.5	20.5	19.5	18.5	18.5	18.5	17.5	15.7	17.5
12. Andaman & Nicobar Is	20.7	20.7	21.7	22.5	22.5	21.5	21.5	21.5	21.5	21.5	21.5	21.0	21.5
13. Lakshadweep Is.	19.7	19.7	20.7	21.7	21.7	20.7	19.8	19.5	19.7	19.7	21.2	19.7	20.3

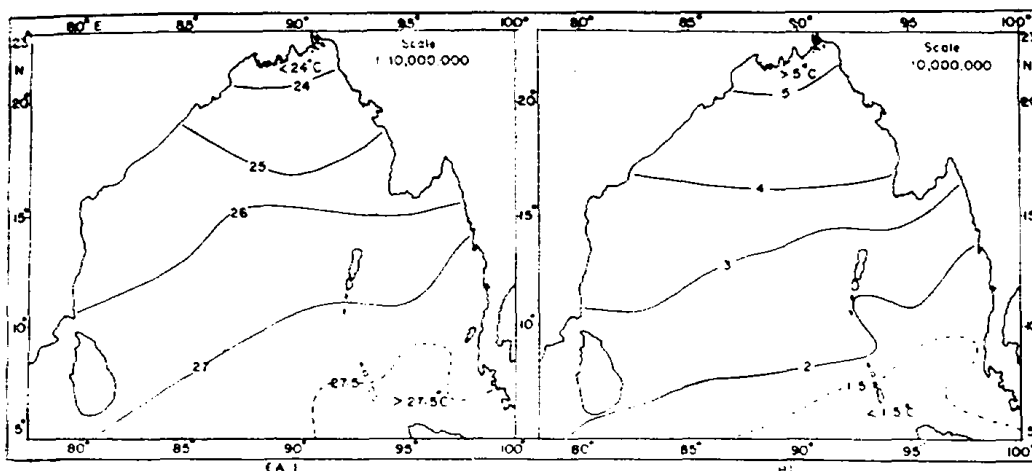


Fig. 3. (A) Mean minimum surface temperature, and (B) Mean annual range of surface temperature in the Bay of Bengal.

Temperature at 1000 m depth

The temperature distribution at 1000 m depth (Fig. 4) shows an interesting feature. The temperature slowly increases northward from 7°C to about 8.5°C along the west coast while it is steady at about 6.5°C along the east coast. Thus adequate thermal gradients ($> 20^{\circ}\text{C}/1000\text{ m}$) are available throughout the year in the Bay of Bengal and the southern Arabian Sea for extraction of ocean thermal power (Table II). Based on the thermal gradient data and the proximity of the coast to deep waters, priority could be given to three locations; the first one off Lakshadweep Islands, the second off Nicobar Islands and the third off the central east coast of India.

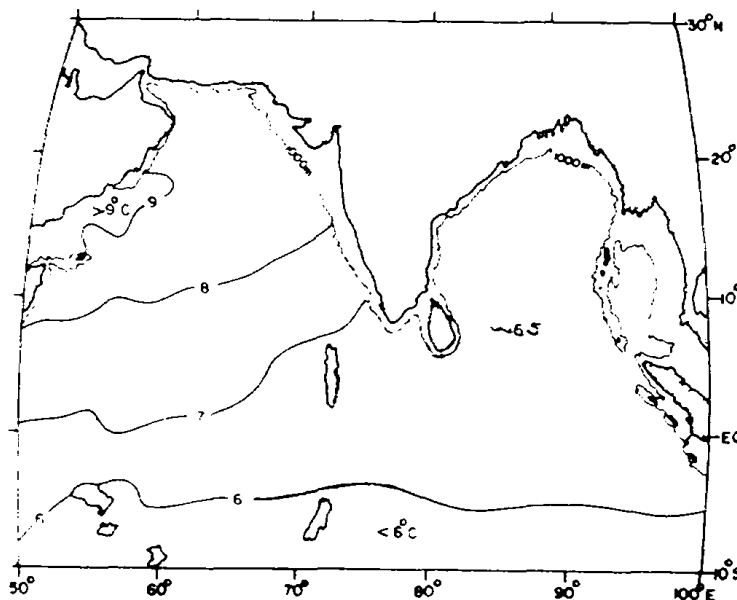


Fig. 4. Temperature at 1000 m depth.

Thermal efficiency and OTEC site potential

The seasonal variation of thermal efficiency closely follows that of SST (Fig. 5) showing again two maxima corresponding to early summer and autumn seasons and two minima corresponding to winter and late summer seasons except in the northern regions off Paradip and Porbander and off the east coast of Andaman and Nicobar Islands where only one maximum and one minimum encountered during early summer and winter respectively. In general, the areas off Sacramento, Divi Point, Krishnapatnam and Pondicherry along the east coast of India and off the east coast of Andaman and Nicobar Islands possess high thermal efficiency ($>7.0\%$) (Table III). Among them the area off Krishnapatnam is of the most promising site on the east coast of India in respect of both temperature difference (21.2°C) and proximity of 1000 m isobath to the coast (23 km). In this connection it would be appropriate to mention that Tamil Nadu Electricity Board (TNEB) has already proposed to set up one OTEC plant off the Tamil Nadu coast and for this purpose, Kulasekharapatnam has been selected out of the four promising sites, three off Pondicherry and Cudalore area and one off Tuticorin coast, for carrying out pilot studies. If distance from the coast to the deep sea is taken as the main criterion for selection of a site, Pondicherry (Markanam) has advantage over other areas but Kulasekharapatnam which is a little south of Pondicherry is relatively free from storm disturbances.

OTEC site potential which is the ratio of mean annual of thermal efficiency to the distance of the site from coast has been computed for all locations and presented in Table III. Lakshadweep Islands have the highest site

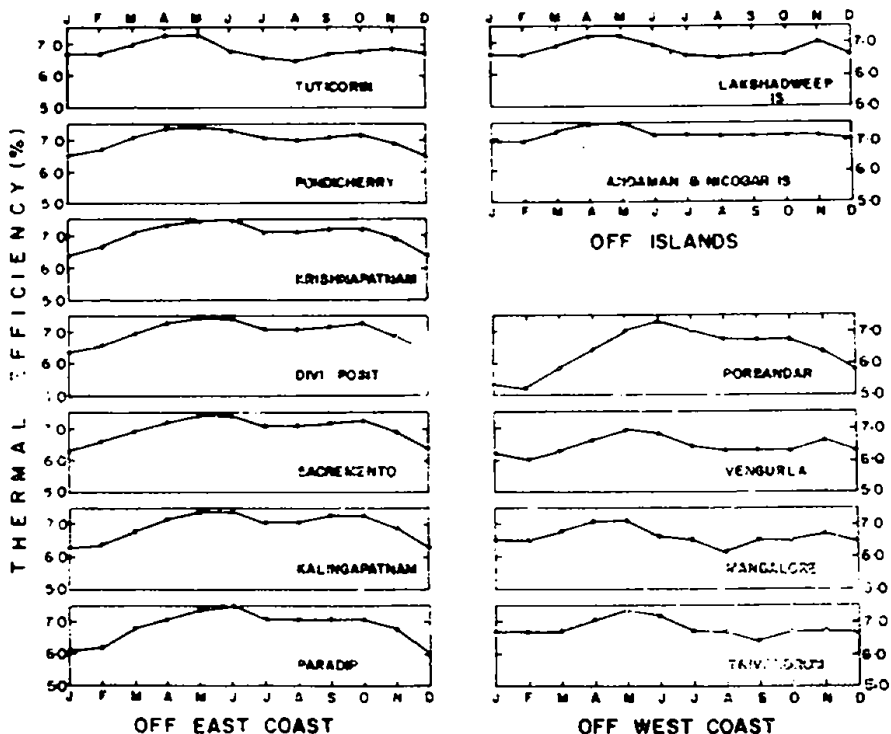


Fig. 5. Seasonal variation of thermal efficiency at some off-shore sites.

Table III. Thermal efficiencies and OTEC Site potentials at some off-shore locations.

Locations (off)	Annual range of thermal efficiency (%)	Mean annual thermal efficiency (%)	Distance from the coast (km)	OTEC site potential
Paradip	6.12 — 7.67	6.89	42	0.164
Kalingapatnam	6.39 — 7.57	6.98	43	0.162
Sacramento	6.45 — 7.57	7.01	35	0.200
Divi Point	6.48 — 7.56	7.02	28	0.251
Krishnapatnam	6.52 — 7.54	7.03	23	0.306
Pondicherry	6.55 — 7.50	7.02	28	0.251
Tuticorin	6.54 — 7.16	6.85	39	0.176
Trivandrum	6.47 — 7.15	6.81	58	0.114
Mangalore	6.29 — 6.94	6.61	81	0.082
Vengurla	6.00 — 6.87	6.43	100	0.064
Porbandar	4.98 — 6.72	5.85	98	0.060
Andaman & Nicobar Is.	6.87 — 7.42	7.14	23	0.310
Lakshadweep Is.	6.45 — 7.07	6.76	4	1.690

potential value (1.69) because the deep waters are only about 4 km. away from the coast. Another promising area for setting up an experimental plant is off the south east coast of Great Nicobar Island where deep waters are encountered within 9 km from the coast.

The power requirements of Lakshadweep, Andaman and Nicobar Islands are at present largely met from sources like oil and coal shipped from the mainland. Transportation of oil and coal to the islands is expensive and the production costs of electricity in these remote islands are mainly dependent on shipping charges which are again linked up with crude oil prices. According to Cohen (1979), the production cost of OTEC power in USA is estimated to be about 5 cents per kilowatt-hour which will be less compared to the projected costs of power derived from conventional sources like coal and diesel for the next 10-20 years. OTEC power may, therefore, be economically viable at the island sites. However, it is suggested here that, before going for commercialisation of OTEC power, precise oceanographic data should be obtained first to design an experimental plant producing a net power of about 1 MW in the areas off these islands, especially off Lakshadweep, in order to test various systems of the power plant under ocean conditions and also to evaluate the effect of plant operations on environment. However, aspect such as corrosion and biofouling which affect heat transfer across the exchangers whose cost forms a major part in the OTEC plant capital cost, nature of the sea-floor for laying down underwater cables between the plant and the coast and weather conditions, especially the storm frequencies, must be considered simultaneously at these sites before taking final decision to set up the OTEC plant.

ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks to Dr. S. Z. Qasim, former Director, National Institute of Oceanography, Goa for his encouragement and to Dr. B. U. Nayak, Head, Ocean Engineering Division, NIO, for his critical comments.

REFERENCES

- Cohen, M., 1979. Energy from ocean thermal gradients. *Oceanus*, **22** : 12-22.
- Dunn, H.S., 1977. Optimization of an ocean thermal energy conversion system. *Ocean Engineering*, **4** : 23-39.
- Koninklijk Nederlands Meteorologische Institut. 1952. *Indian Ocean Oceanographic and meteorological data*, No. 134, Royal Netherlands Meteorological Institute. De Bilt, Netherlands, 31 pp, 24 charts.
- Ramachandran, A. and J. Gururaja, 1977. Perspectives on energy in India. In : *Annual Review of Energy*, Vol. 2, edited by J.M. Hollander, Annual Reviews Inc., Palo Alto, California, 365-386.
- Wyrtki, K., 1971. *Oceanographic Atlas of the International Indian Ocean Expedition*. National Science Foundation, Washington, D.C., 531 pp.