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Study of thermal structure of some stratified reservoirs in India

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Abstract
Temperature of water body is an important parameter which influence various physical, chemical and biological processes and inturn has effect on aquatic life. Large reservoirs and lakes which have negligible through flows during non-monsoon periods exhibit thermal stratification due to water temperature variation over the depth. This thermal structure undergoes seasonal changes. The waste heat disposal from power plants to water bodies also adds to these stratification effects. The temperature stratification data of some reservoirs in India (including some loaded with thermal discharges) has been analysed in the paper in view of importance of water temperature for engineering and environmental process.

INTRODUCTION

Stratification in the reservoirs or lakes with large depths (generally over 10 m to 20 m) and volumes is observed due to variation in water temperature, salinity and suspended silt load over the vertical. Such stratification leads to division of the water body into horizontal layers. For inland reservoirs and lakes variation of water temperature over the depth leads to thermal stratification. The thermal stratification structure of the inland reservoir water body is influenced by number of factors such as solar radiation, wind velocities on water surface, through flow in the reservoir, heat transmission characteristics of water body, heat sink or source (in the form of cooling water intake and hot water outfall) in reservoir and the season of the year. Study of thermal structure of the water body is important from many engineering as well as environmental aspects. This is because the water temperature is a very vital parameter which affect the physical and bio-chemical processes. The physical properties of water such as density, viscosity, vapour pressure, surface tension and dissolved oxygen change with change in temperature. With water temperature rising there will be reduction in density, viscosity, surface tension and dissolved oxygen, where as the vapour pressure will increase. Water is universal solvent and its solubility changes with temperature. Many bio-chemical processes related to aquatic life are function of water temperature. Therefore, knowledge of thermal structure of water bodies is important for study of various related engineering as well as environmental issues. The vertical temperature profiles of five Indian reservoirs were studied. The monthly variation of thermal stratification of one of the reservoirs were also studied. Four out of these five reservoirs are presently serving as cooling reservoirs for the thermal power plants in addition to other functions. The thermal structure of these reservoirs has been analysed.

TYPICAL STRUCTURE OF STRATIFIED RESERVOIR

Fig.1 shows a typical vertical temperature profile of a stratified reservoir in summer.

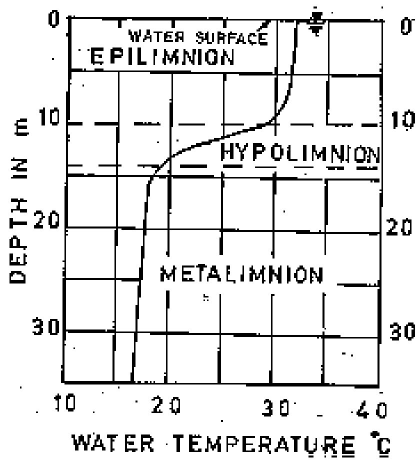

Figure 1. Typical vertical temperature profile in stratified reservoir.

The temperature profile divides the reservoir horizontally in three distinct zones. The upper zone is known as epilimnion. The water temperature in this zone is more or less uniform or there could be gradual reduction in temperature by about 1^0C to 2^0C form water surface to the bottom of epilimnion. In many cases the variation of temperature is very small (below 0.5^0C). This is mainly because there could be good vertical mixing in epiliminion due to ambient as well as wind generated currents and waves. The depth of epilimnion could be from 5 m to 10 m. Zone below epilimnion is called as metalimnion. In metalimnion rapid reduction in temperature takes place in downward direction (Fig.1) in relatively short distance. Infact the temperature curve passes through the point of inflection where the sign of the slope of curve changes. The depth of this zone could vary from 2 m to 4m. The temperature drop across the metalimnion could be 4^0C to 8^0C. The reservoir zone below metalimnion is known as Hypolimnion. The temperature in this zone is normally uniform or there could be further drop in water temperature of about 1^0C to 2^0C over vertical. The depth of Hypolimnion could be large for deep reservoirs.

THERMAL STRUCTURE OF SOME INDIAN RESERVOIRS

The temperature data of the five reservoirs namely Maithon (Bihar), Rihand (U.P.), Satpura (M.P.), Obra (U.P.) and Ranapratapsagar (Rajasthan) was studied. The salient features of these five reservoirs are given in Table 1. The water temperature data of Maithon (1968) and Rihand (1977) could be treated as ambient data since there was no hot water disposal in these reservoirs during the period of data. The remianing reservoirs (Satpura, Obra and Ranapratapsagar) have through flow of hot water discharge of about 46 m^3/s, 17 m^3/s and 28 m^3/s respectively throughout the year. In case of Obra there is additional through flow of 566 m^3/s for 1 to 4 hours daily due to hydropower generation at Rihand and Obra dams. For these reservoirs the temperature data at many locations in the reservoirs is available. However, for these studies the temperature data at location 3 km to 5 km away from hot water outfall location was utilized. Practically there was negligible effect of hot water disposal on the vertical temperature gradients at these selected locations.

Table 1. Salient features of reservoirs studied.

Sr.	Item	Reservoirs				
No	Description	Maithon	Rihand	Ranapratap sagar	Satpura	Obra
1	State	Bihar	U.P	Rajasthan	M.P.	U.P
2	River	Barakar	Rihand	Chambal	Tawa	Rihand
3	Capacity at FRL Million m^3	1370	10600	2860	80	211
4	Reservoir area at FRL (Ha)	10700	46600	19800	1000	1425
5	Maximum depth (m)	40	90	40	15	15.5
6	Hydropower Capacity (MW)	60	300	Nil	Nil	99
7	Non-monsoon through flow (m^3/s)	Nil	Nil	28.4	46.0	566

Table 2. Comparison of thermal structures of 5 reservoirs.

Parameter / item	Reservoirs					Remarks/ overall
	Satpura	Obra	Rana-pratap-sagar	Maithon	Rihand	Variation
Epilimnion i) Thickness	5.5 m	3.5 m	10.0 m	10.0 m	10.0 m	4 m to 10 m
ii) Surface temperature	31.0^0C	29.5^0C	30.0^0C	31.0^0C	31.0^0C	29^0C to 31^0C
iii) Temp. drop in epilimnion	1.0^0C	0.5^0C	0.5^0C	1.0^0C	1.0^0C	0.5^0C to 1^0C
Metalimnion i) Thickness	3.0 m	4.0 m	2.5 m	4.0 m	4.0 m	2.5 m to 4.0 m
ii) Temperature variation	29^0C to 27^0C	29 to 23^0C	28^0C to 22^0C	29^0C to 24^0C	29^0C to 23^0C	29^0C to 22^0C
iii) Temp. drop in metalimnion	5^0C	6^0C	6^0C	4^0C	6^0C	4^0C to 6^0C
Hypolimnion i) Temperature	22^0C	22^0C	20^0C	24^0C	20^0C	20^0C to 24^0C
ii) depth below water surface where hypolimnion begins	8.5 m	7.5 m	12.5 m	14.0 m	14.0 m	7.5 m to 14 m
Temp. gradient over entire epth	9^0C	8.5^0C	8.0^0C	7^0C	11^0C	7^0C to 11^0C

Fig.2 shows comparison of water temperature gradients over vertical during month of May in these five reservoirs. It could be seen from Fig.2 that, all these reservoirs follow the general trend for stratified reservoir indicated in Fig.1. Three zones of reservoir i.e. Epilimnion, Hypolimnion and Metalimnion are distinctly seen in all reservoirs. There is temperature gradient of about 7^0C to 12^0C from surface to bed. The surface water temperature varied from 29^0C to 32^0C in different reservoirs with an average of 30.5^0C. The temperatures near bed varied between 19^0C to 22^0C in most of the reservoirs with an average value of about 20.5^0C. Table 2 shows more detailed comparison about thermal structure of these reservoirs.The comparison of temperature gradients shown in Fig.2 and in the Table 2 indicate following important facts :

Surface water temperatures in epilimnion vary between 29^0C to 31^0C.
Epilimnion thickness varies from 4 m to 10 m. This variation could be due to difference in ambient flows and wind conditions which enhace vertical mixing.
The temperature drop through epilimnion is negligible (0.5^0C to 1.0^0C) inspite of large thickness.
Thickness of metalimnion varies from 2.5 m to 4.0 m for different reservoirs.

Temperature drop by about 4^0C to 6^0C through metalimnion so as to give temperatures of about 22^0C near junction of metalimnion and hypolimnion.
In hypolimnion, water temperatures are about 20^0C to 24^0C. The drop in water temperature within hypolimnion is restricted to 0.5^0C to 1.0^0C only.
The reservoirs loaded with hot water discharges also indicate nearly same thermal structure (as that of ambient reservoirs) at distance 3 to 5 kms away from hot water outfall.

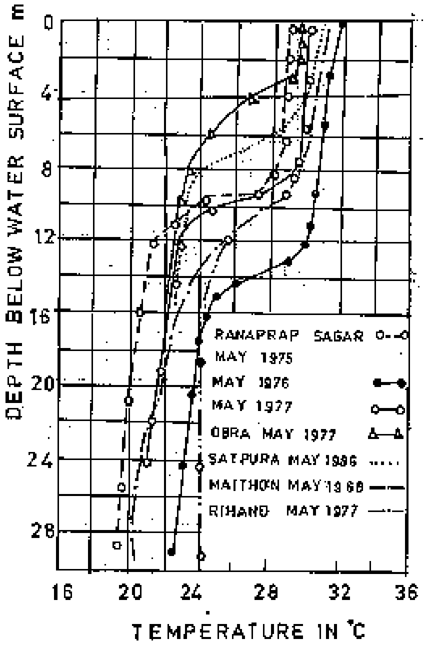

Figure 2. Comparison of temperature gradients in some Indian reservoirs.

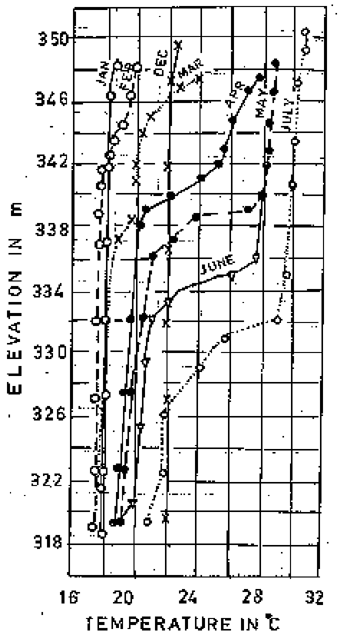

Figure 3. Monthly variation in temperature gradient of Ranaparatapsagar Reservoir.

SEASONAL / MONTHLY VARIATIONS IN THERMAL STRUCTURE

Though the water body has high thermal inertia, the vertical temperature distribution in reservoir undergoes gradual changes due to various heat transfer processes within water body as well as across air - water interface. These processes are governed by various parameters such as through flows, solar radiation intensity, seasonal changes in water flow and wind velocities and so many other meteorological parameters such as air temperature, humidity etc. Depending upon total storage volumes and the depths the reservoirs may even become well mixed or partially mixed. Fig.3 shows comparison of vertical temperature gradients of Ranapratapsagar reservoir during different months of the year. From Fig.3 it could be seen that the reservoir is well mixed with uniform temperature of about 18^0C during January in winter season. From February onwards gradually surface temperature and the epilimnion depth increase. The process of formation of stratification continues in March - April. In May well developed thermal stratification prevails in the reservoir. In June - July the epiliminion depths increase due to increased level of turbulence in epilimnion on account of monsoon flows and wind. Reservoir gets well mixed during monsoon and overall temperatures drop. Till December reservoir reaches uniform temperature of 22^0C over entire depth. Study of Fig.3 shows that the depths of epilimnion and metalimnion undergo changes from month to month and season to season. Surface temperature change from 31^0C in May - June to 20^0C in January. Temperatures in hypolimnion change from 18^0C to 22^0C. The depths of different zone in Ranapratapsagar reservoir in May, June and July are shown in Table 3 below.

Table 3. The depths of different zone in Ranapratapsagar reservoir in May, June and July.

Month	Reservoir	Depth (m) of		
	Conditions	Epilimnion	Metalimnion	Hypolimnion
May	Bright sunshine, moderate winds, well stratified, and stable gradient	8	4	18
June	Winds, monsoon flows increase turbulance	12	4	14
July	monsoon through flows, enhance vertical mixing	18	6	6

The most of the reservoirs in India undergo variation in thermal structure due to monsoon flows, wind and seasonal changes in meteorological parameters as demonstrated by Ranapratapsagar. For the reservoirs having total annual inflows much more than the storage volume the thermal structure may get disturbed during early monsoon period. For Ranapratapsagar the ratio of annual inflow to capacity is close to 0.9. The reservoirs with the ratio much smaller (0.1 to 0.2) may be able to sustain stratification effects for a longer time during monsoon.

Table 4. Cooling water systems of some power plants.

S. No	Project	Capacity	Cooling Water Discharge	Total Reservoir area	Dist. Bet. Intake & outfall	Area bet. Intake & outfall	Details of Skim. wall Intake A	B	C	Outfall W	D
		MW	m^3/s	Hect.	Km	Hect.	m	m	M	m	m
1	Satpura Thermal Power Station	1142.5	46.6	1000	4.00	200	9.0	325	2.5	16	4.2
2	Obra Thermal Power Station	1550	77.0	1450	0.35	100	10.5	77	5.0	75	3.7
3	Korba West	1260.0	51.0	1210	5.00	600	*	*	*	10	2.0
	Korba East	440.0	17.0	1210	2.70	400	4.0	60	3.0	6	2.0
4	Birsing-pur Thermal Power Station	1420.0 (Proposed)	57.0	1150	1.30	300	7.00	100	4.0	60	3.0
5	Kaiga Nuclear Power Station	1410.0 (Proposed)	97.0	2650	2.00	350	10.0	161.2	4.0	20	5.0

Note : A - Depth of water above skimmer wall opening
B - Length of skimmer wall opening
C - Depth of opening
W - Width at Outfall
E - Depth at Outfall
* - No skimmer wall

IMPORTANCE OF THERMAL STRUCTURE OF RESERVOIR

The knowledge of thermal structure of the reservoirs is important for many engineering as well as environmental problems. Most important engineering problem is the design of cooling water intake and hot water outfall for thermal and nuclear power projects using lakes as cooling ponds. The cooling water with temperature of 20^0C to 24^0C is required on large scale for these power plants. For the assured supply of this cooling water, the intake with skimmer wall structures are designed for selective withdrawal of water from cool layers of Hypolimnion. The entry of high temperature water from Epilimnion into intake is avoided by skimmer wall intake with top of opening located in Hypolimnion. The cooling water coming out of condenser has temperature of about 8^0C to 10^0C higher than the intake temperatures. Thus, the hot water temperature could be 30^0C to 35^0C. This hot water could be discharged back into epilimnion of the lakes so that temperature rise in the lake environment could be kept at permissible levels. Knowledge of thermal structure of reservoirs is thus important for the planning and design of cooling water intake and outfall structures of power plants. Following Table shows details of cooling water intake and hot water outfall for some power projects in the country which were designed on the basis of model studies and field observations.

The water temperature is a vital parameter and it controls various physical, chemical and bio-chemical processes and influences many parameters pertinent to the nutrients and life cycle. Any major variation in ambient water temperature could disturb aquatic biota and ecological balance. In view of this, the Ministry of Forest and Environment has enforced environment protection Act of 1986 stipulating restrictions on temperatures of industrial effluent at discharge (point) including hot water from power plant. For power plant hot water discharges in to inland reservoirs/ rivers the temperature of effluent should not exceed the ambient temperature of receiving water body by more that 5^0C. The knowledge of the ambient thermal structure of the reservoir can be useful to predict the possible maximum effluent temperatures.

In general the water temperature change from 10^0C to 40^0C will results in reduction in Density (7%), Viscosity (50%) Surface Tension (6%), and Oxygen Solubility (41%). Reduction in density and viscosity will lead to increased sedimentation and stratification. Reduction in surface tension will enhance mixing at water surface. Normally rate and extent of chemical reactions become double for every 10^0C rise in temperature. Micro-organism which are part of flood chain in aquatic environment become more active with increase in temperature. The rate of Oxidation also increase with temperature resulting in increase in BOD. The temperatures in excess of critical temperature lead to destruction of proteins and enzymatic systems of organisms. This results in changes in rate of growth respiration, reproduction and death of organism.

Following are general biological effects either known / observed or concluded by research :

Beyond certain limiting temperature a rapid die-off of organisms may occur.
Warm water fish may survive in the temperatures more than 34^0C. Ultimate lethal temperatures vary from 25^0C to 40^0C for different species of fish.

Fish have ability to adopt to higher temperatures faster than to lower temperature. Therefore, sudden exposure to low temperature is more harmful than gradual rise in temperature. Adult fish can easily tolerate higher temperatures than the younger population.

The fish may starve at higher water temperatures due to increased respiratory rates on account of reduction in dissolved oxygen and food requirement.

Fish and other aquatic organisms are capable of moving to zone of preferred temperatures.

Fish can reproduce successfully in restricted temperature ranges.

CONCLUDING REMARKS

During the summer, the maximum Surface water temperature in reservoirs in North India could be between 29^0C to 32^0C under ambient conditions. The temperatures in hypolimnion zome could be around 22^0C to 18^0C depending on the season.

The reservoirs with depths more than 10 to 15 m exhibit stable temperature gradient during summer with temperature variation of about 7^0C to 12^0C over vertical.

The wind, waves and the ambient through flows in the reservoirs may disturb or totally destroy thermal stratification in the reservoir. The reservoir may undergo seasonal changes in thermal structure.

Heated discharges from power and other industries may have very little effect on thermal stratification pattern in the reservoir especially away from outfall. However, there could be some change in thermal pattern around the outfall location.

Knowledge of thermal structure of the reservoir could be of great help in many engineering and environmental problems.

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