STRATIFICATION INVESTIGATION IN AN ENERGY STORAGE TANK

SHEHERAZAD Y. EZZELDEEN*

* *Basic Engineering Sciences Department, Faculty of Engineering, Minufeya University, Shebin El Kom, Egypt*

ABSTRACT

The need to consider renewable energy increases everyday. In solar energy systems, thermal stratification plays an important role that should be well investigated. This paper deals with the stratification behavior found in a cylindrical energy storage tank. The tank was filled with water introduced through two different inlets, and test cases were studied for charging and discharging modes. Discharging mode was studied with circulation and without circulation. The stratification behavior was studied under different conditions of inlet temperatures and different inlet pipe locations: horizontal and vertical. It was found out that the horizontal inlet is better for achieving a higher stratification for the charging mode at a flow rate of 50 L/hr and a temperature of 50°C . It was also found out that the horizontal pipe led to a better stratification behavior for the discharging mode without circulation. As for the discharging mode with circulation, the results showed that the vertical pipe led to a better stratification.

1. INTRODUCTION

Everyday the demand on energy increases. In Egypt, the per capita electricity generation changed from 1312 kWh/Capita in 2000 to 1350 kWh/Capita in 2001. The per capita primary energy consumption increased from 696 kilogram oil equivalent (kgoe) in 2000 to 722 kgoe in 2001 [1]. Renewable energy provides an immense source of energy that is not yet exploited as it should be in Egypt. Therefore, renewable energy, especially solar energy, should get greater attention, since it is available through the whole year in addition to its being a non-polluting source.

In solar energy systems, since hot water is less dense than cold water, the hot water rises to the top of the tank while the cold water gets to its bottom; therefore, stratification usually occurs in the storage tank . This stratification is useful, as it improves the performance of the solar heating system; the coolest water is sent to the collector while the warmest could be sent to any heating equipment . As time passes by, the whole water of the tank will be circulated and heated and this improves the energy of the water in the tank.

In the literature reviewed, studies were conducted to investigate the performance of the energy storage tanks. Shah and Furbo performed a theoretical and experimental analysis of water jets entering a solar tank and measured the temperature stratification in the tank [2]. Burch et al performed a model calibration and defined a method for testing integral collector storage solar systems. The calibrated model presented underpredicted delivered energy over a 5-day period of normal operation by 11%, because of the lack of modeling for the tank stratification [3]. Mather et al investigated a multi-tank liquid water system for storing low temperature solar-derived heat [4]. Other studies also identified some of the parameters related to the performance of these tanks[5-12].

2. EXPERIMENTAL TECHNIQUES

2.1 Equipment Setup

A water storage system was assembled. It consists of a supply tank fitted with a heater, a pump, a flow meter, the storage tank and the conducting pipes.

The storage tank, which is 1m high, of 0.5m inner diameter, is insulated with 6 cm thick glasswool. The thickness of the tank is 3mm. It is provided with a cover of 70 cm diameter. Holes have been perforated for bolts in both the cover and the upper edge of the tank, each of them is 1cm diameter. These holes allow the flow of fluid in and out of the tank. The cold water enters the supply tank where it is heated to the desired temperature, it is then pumped to the storage tank. Side wall tubes were welded to the outer shell of the tank. The horizontal tube which was used in this study is at 80 cm from the bottom of the tank. In addition, another tube was welded to the upper cover of the tank at a distance of about 17cm from the center of the cover to allow the flow of hot water from the supply tank to the storage tank . Valves were mounted on these tubes so that only one given inlet pipe is used at a time. The tank was provided with a level indicator and a vent. Figure 2.1 is a schematic representation of the apparatus and instrumentation used.

Twenty four thermocouples were provided to record the temperature distribution inside the tank on a special stand where they were installed. This stand consisted of a central steel pipe carrying twelve horizontal steel rods at three different levels: 4 rods at each level. Figure 2.2 illustrates the mounting of the rods and thermocouples on the stand inside the tank.

The water flow rate was measured using the flow meter mounted on the pipe connecting both the supply and storage tank. It was kept constant for the experiment at the desired value by adjusting the bypass fluid through the bypass valve as illustrated in Fig. 2.1.

2.2 Methods of Testing

A low flow rate was used in order to obtain maximum storage energy fast. The better altitude for the horizontal pipe was used, that is at a height of 80 cm from the bottom of the tank, since this horizontal inlet pipe gives the maximum energy storage [7]. The temperature was measured each 10 minutes at all thermocouples locations during the experiment.

Charging Mode

Both the storage and the supply tanks were filled with water by opening valves V1and V3. When they are completely filled, the valve V1 was then closed. The operation of the electric heater and the pump is then started. Hot water is pumped to the tank by opening any of the valves V4, cold water was taken out through valve V3, and taken back to the supply tank.

Discharging Mode

In this mode, hot water is taken from the storage tank via valve V2, valve V5 is opened.

a. Discharging without circulation

Valves V1, V3 are closed, so that cold water flows to the supply tank where it is heated and then pumped to the storage tank through one of the valves V4. The flow in and out of the two tanks was maintained at constant rate to obtain steady state flow.

b. Discharging with circulation

V3 and one of the inlet valves V4 are opened. Again, a certain amount of water is discharged, balanced by an equal amount of inlet water.

The Stratification Index (SI) is used to describe the degree of mixing inside the storage tank. The higher the SI, the stronger the stratification inside the tank and the weaker the mixing behaviour. The stratification index ranges from 0 to 1, with zero representing a perfectly stratified (unmixed) tank and 1 representing a fully mixed tank.

The height of the tank was considered to be divided into three regions for measurements. These are:

Level A is the distance from the top of the tank till half the distance between the first and second horizontal rods carrying the thermocouples

Level B is the distance from the bottom of level A till half the distance between the second and third horizontal rods carrying the thermocouples

Level C is the distance from the bottom of level B (half the distance between the second and third horizontal rods carrying the thermocouples) till the bottom of the tank .

The stratification index (SI) can be defined as:

$$SI = \frac{T_{Aav} - T_{Cav}}{T_{in} - T_{initial(A,C)}}$$

where:

T_{Aav}: Average Temperature at level A inside the tank at any time

T_{Cav}: Average Temperature at level C inside the tank at any time

$T_{initial(A,C)}$: The average initial temperature for both levels A & C

T_{in}: Maximum temperature supplied by the heater

A normalized form of time and was used.

The dimensionless time =time/(Tank volume/volumetric flow rate)

3. RESULTS AND DISCUSSION

Figure 3.1 shows the variation of the stratification index with dimensionless time for the charging mode for the two different inlets at a flow rate (Q) of 50 L/hr and inlet water temperature of 50°C. For the horizontal pipe (inlet 1), SI increased gradually with dimensionless time till it reached a peak value of 0.9 at a dimensionless time of 0.2, then it decreased gradually to nearly reach an asymptotic value of 0.02 after a dimensionless time of 0.56. The same pattern was found for the vertical pipe (inlet 2) since the stratification index increased also gradually with time to reach a peak value of 0.45 at a dimensionless time of 0.12, then it decreased gradually to almost reach an asymptotic value of 0.01after a dimensionless time of 0.48.

It is to be noted that at these conditions, the highest stratification index inside the tank is obtained for the horizontal inlet. The lowest stratification index is obtained for the vertical inlet. For the horizontal pipe the rate of increase of SI was fastest with dimensionless time followed by faster decrease compared to the vertical one. The trend of stratification is independent of the inlet location. It is also to be noted that at this temperature the stratification index is all the time higher for the horizontal pipe than for the vertical one. Figure 3.2 shows the variation of the stratification index for the same inlets and the same flow rate at inlet water temperature of 60°C. Figure 3.3 shows the variation for the same inlets and the same flow rate at inlet water temperature of 70°C.

For these two figures, again almost the same patterns were observed.

Figure 3.4 compares the variation of the stratification index with dimensionless time for the charging mode for inlet 1 at a flow rate of 50 L/hr and different inlet water temperatures. It can be seen that for this inlet the higher stratification takes place with the lower temperature used (50°C). Figure 3.5 shows the variation of the stratification index with dimensionless time for the charging mode for inlet 2 at a flow rate of 50 L/hr and different inlet water temperatures. It can be seen that for this inlet the higher stratification occurs with the highest temperature used in this experiment (70°C).

Figure 3.6 shows the variation of the stratification index with dimensionless time for the discharging mode without circulation for the different inlets at a flow rate of 50 L/hr and inlet water temperature of 50°C. SI increased gradually with dimensionless time till it reached a peak value of 0.95 at a dimensionless time of 0.76, and then almost slowly decreased till a value of 0.85 at a dimensionless time of 1.12 for inlet 1, while it increased gradually with dimensionless time till it reached a peak value of 0.8 at a dimensionless time of 0.56 ,and then almost slowly decreased till a value of 0.41 at a dimensionless time of 1.12 for inlet 2. Figure 3.7 shows the variation of the stratification index with dimensionless time for the discharging mode with circulation for the different inlets at a flow rate of 50 L/hr and inlet water temperature of 50°C. SI increased gradually with dimensionless time till it reached a peak value of 0.59 at a dimensionless time of 0.24 and decreased gradually to reach an asymptotic value of 0.035 a at dimensionless time of 0.64 for inlet 1. For inlet 2, SI increased gradually with dimensionless time till it reached a peak value of 0.63 at a dimensionless time of 0.2 and then decreased till it reached a similar asymptotic value of inlet 1 after a dimensionless time of 0.48.

CONCLUSION

The stratification index in an energy storage tank was calculated at different inlet temperatures of 50°C, 60°C and 70°C for two different inlet pipe locations, the horizontal and vertical positions for the charging and discharging modes.

It was found out that for the charging mode, the horizontal pipe gave a better stratification than the vertical one at all inlet temperatures investigated. As for the horizontal inlet, natural convection allowed hot water to go to the top of the tank because of its low density, while the vertical inlet allowed for the mixing of water layers. For the horizontal pipe, the stratification increases for the same pipe with decreasing temperature. The best stratification occurred at a flow rate of 50 L/hr and at the lower temperature of 50°C.

It was also found out that the horizontal pipe led to a better stratification behavior than the vertical pipe for the discharging mode without circulation. As for the discharging mode with circulation, the results showed that the vertical pipe led to a better stratification than the horizontal one.

REFERENCES

1. Egypt Energy Statistics 2000/2001, Ministry of Electricity and Energy, Organization for Energy Planning, 2001.

2. Shah, L., Furbo, S., Entrance Effect In Solar Storage Tanks, Solar Energy V75 , n4, Oct. 2003, p 337-348.

3. Burch, J. D., Thornton, J.W., Liu, W., Davidson, J. H., Ruby, T. S., Model Calibration from Short Term Test Data for Unpressurized Integral Collector Storage Systems, International Solar Energy Conference 2003, p 311-317.

4. In Gawlik, K., Burch. J., A Model of Radiation Induced Thermal Stratification in an Integral Collector Storage Tank, International Solar Energy Conference 2003, p 319-325.

5. Mather, D.W., Hollands, K.T., Wright, J.L., Single and Multi Tank Energy Storage for Solar Heating Systems: Fundamentals, Solar Energy, v73, n1, 2002 p 3-13.

6. Li, Z., Sumathy, K., Performance Study of a Partitioned Thermally Stratified Storage Tank in a Solar Powered Absorption Air Conditioning System, Applied Thermal Engineering, v22, n11, August 2002, p 1207-1216

7. El-Haggar, S., El-Baz, A., Ezeldeen, S., Thermal Behavior of a Stratified Energy Storage Tank, Modelling, Measurement and Control v54, n 1-2,1996.

8. El Agamawy, H., Solar Storage Stratification Analysis and Test Data Correlation, Proceedings of the 2nd World Renewable Energy Congress, v2, Pergamon Press, Sept 1992.

9. Al Saad, M.A. and Rabadi, N. J., Thermal Stratification Storage Tanks, Alexandria Engineering Journal, v29, n 3, July 1990.

10. Zurigat, Y. H., Liche, P. R., Ghajar, A. J., Turbulent Mixing Correlations for a Thermocline, AIChE Symposium Series, Yilmaz, ed, AIChE n 263, v84, p 160, 1998.

11. Lquan, Z., Thomson, J., Experimental Study of Thermally Stratified Hot Water Storage Tank, Solar Energy, v19, p 519, 1977.

12. Close, D. J., A Design Approach for Solar Processes, Solar Energy, v 11, n 2, p112, 1967.

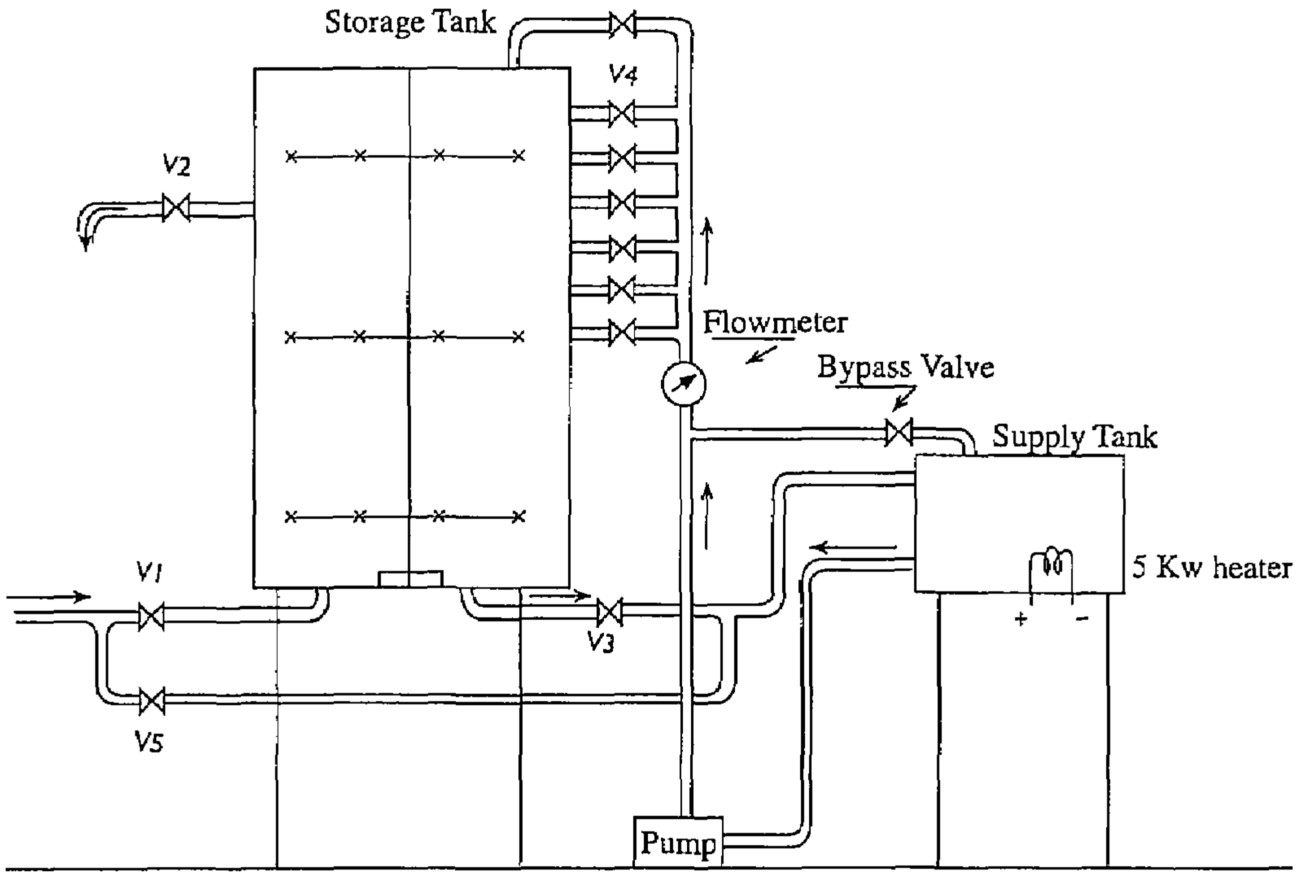

Fig. 2.1 Schematic Representation of the Apparatus

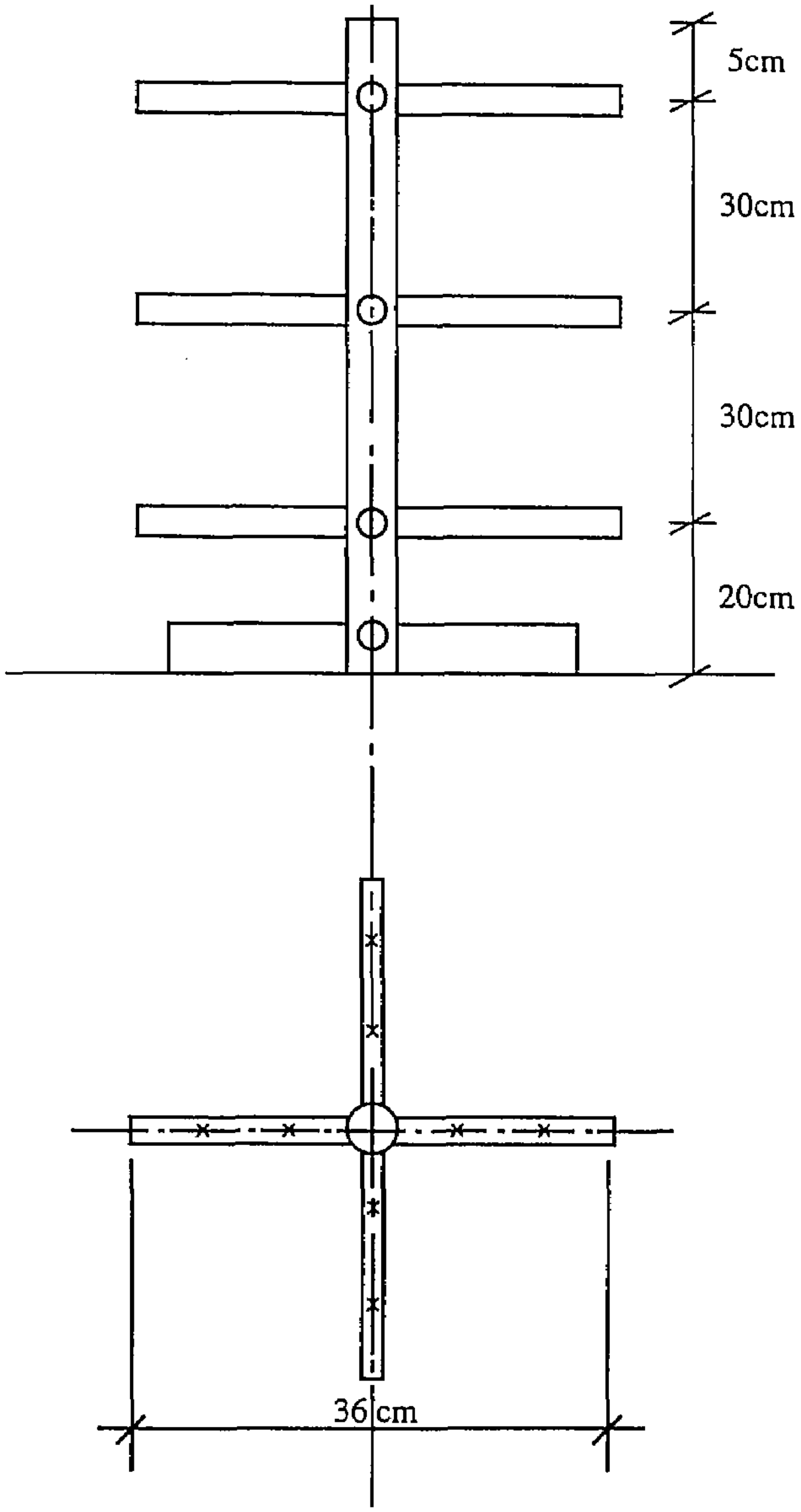

Fig. 2.2 Thermocouples Locations in the Tank

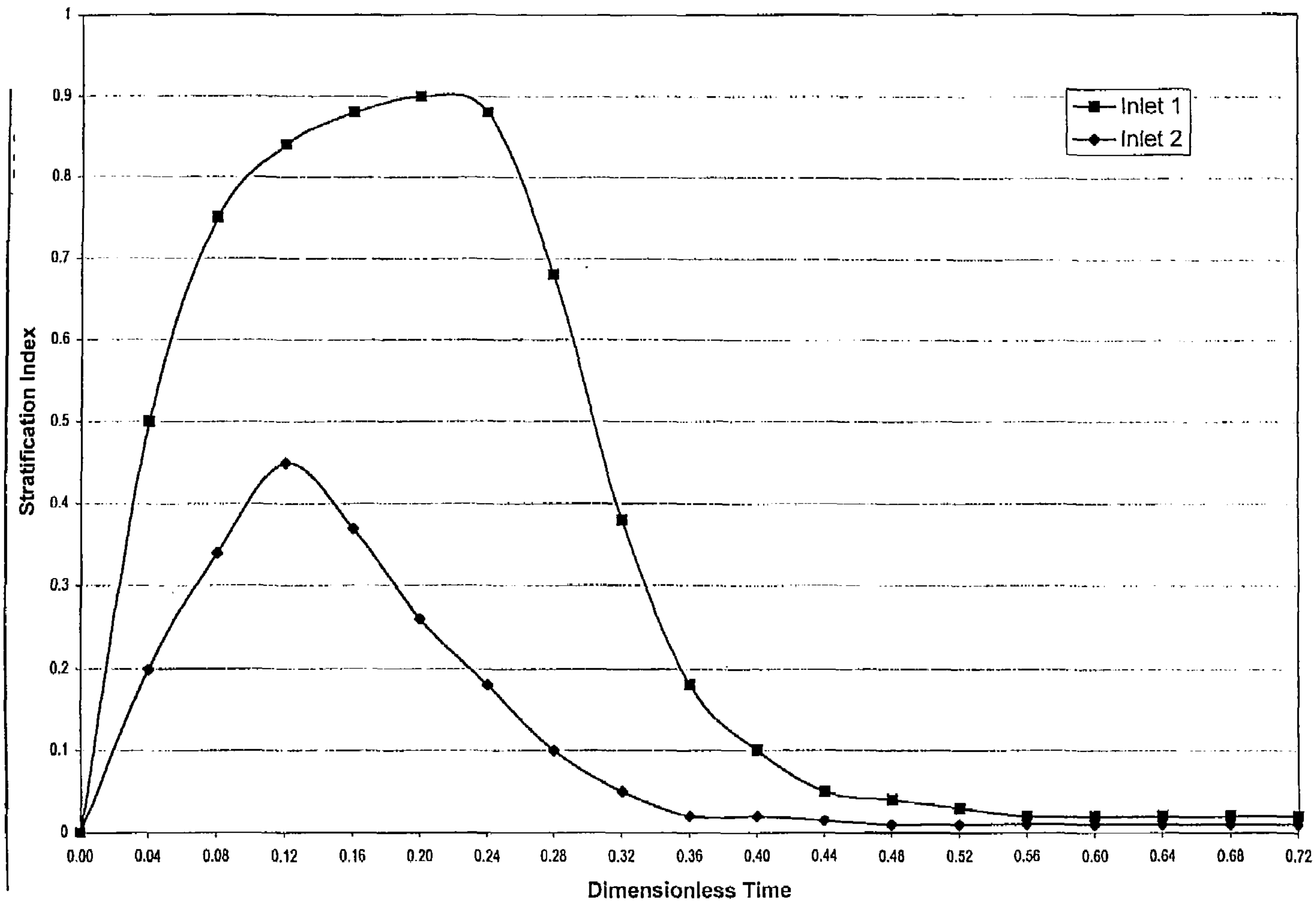

Fig. 3.1 Charging Mode

Variation of Stratification Index with Dimensionless Time for the Inlets

Q=50 L/hr, T_{in}=50°C

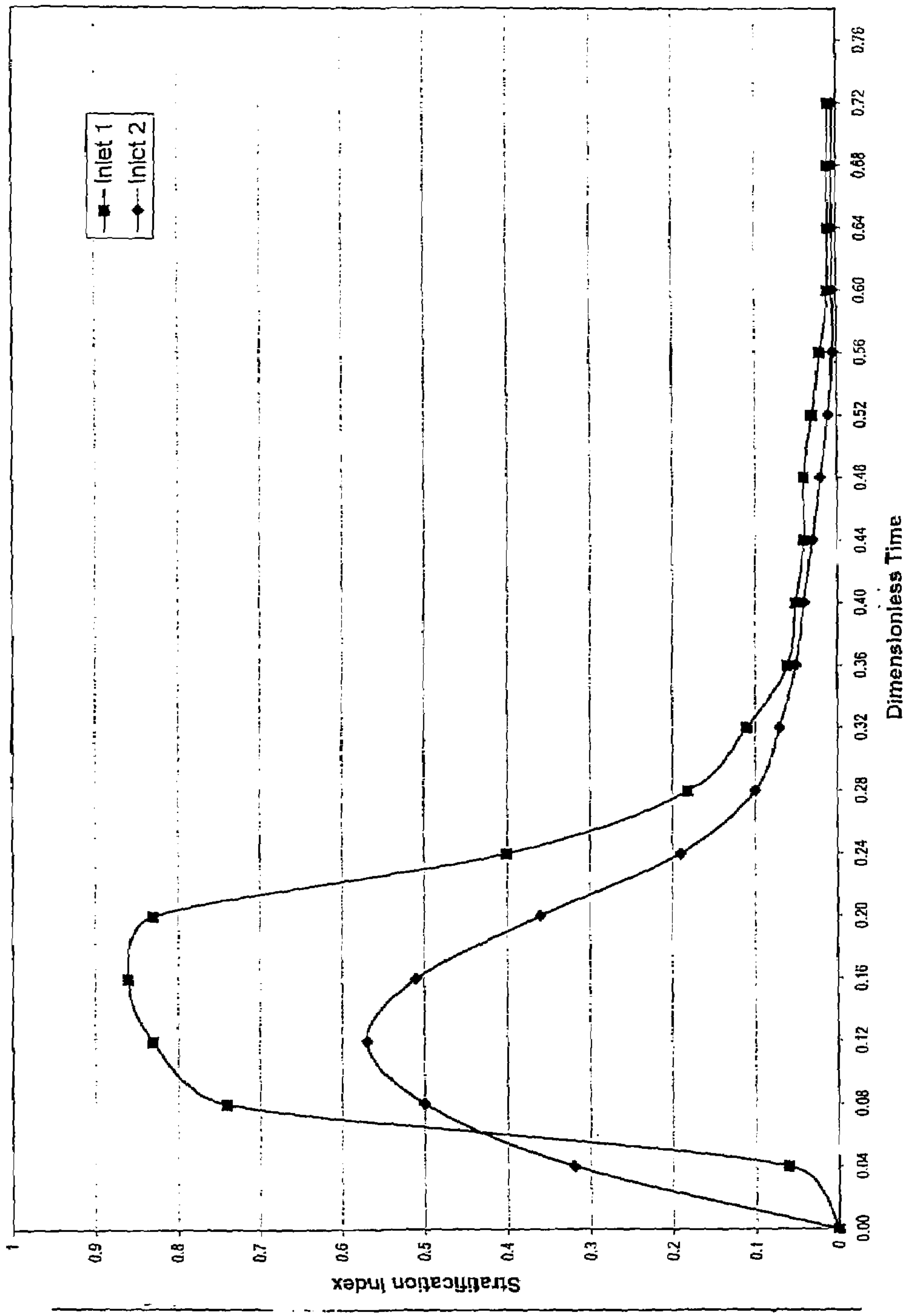

Fig. 3.2 Charging Mode
Variation of Stratification Index with Dimensionless Time for the Inlets
Q=50 L/hr, T_{in}=60°C

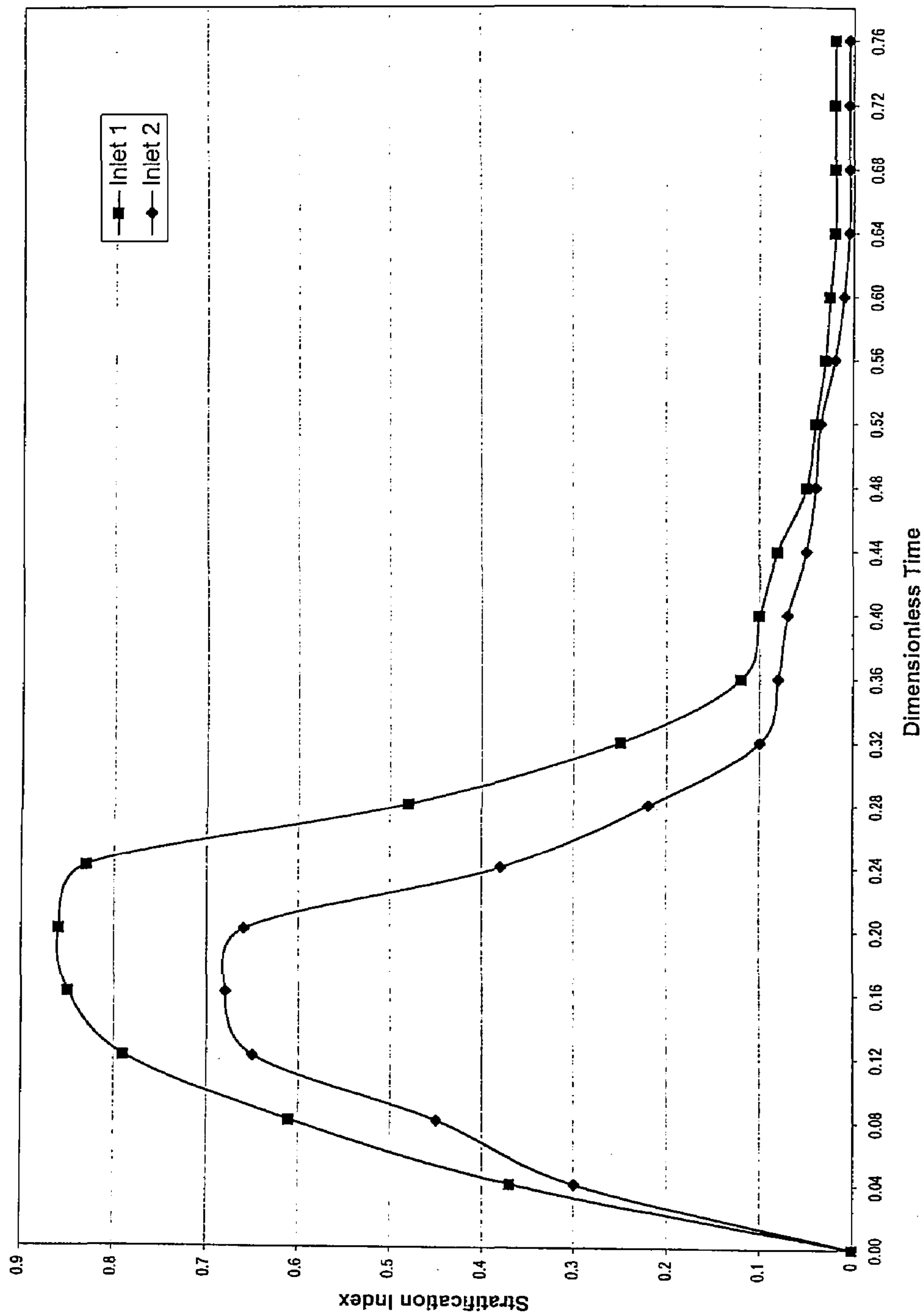

Fig. 3.3 Charging Mode
Variation of Stratification Index with Dimensionless Time for the Inlets
Q=50 L/hr, T_{in}=70°C

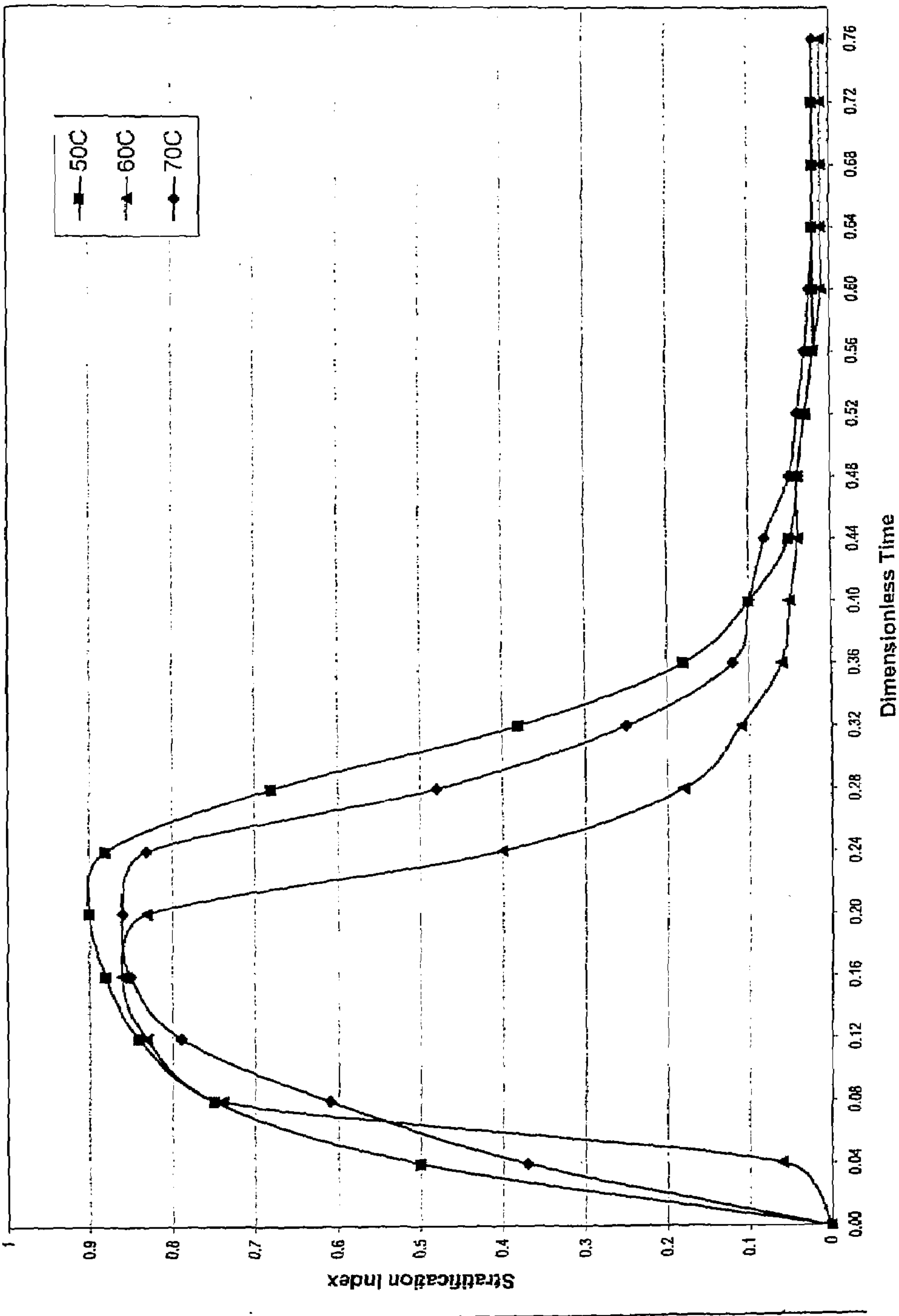

Fig. 3.4 Charging Mode
Variation of Stratification Index with Dimensionless Time for the Inlet 1
for Different Temperatures (Q=50 L/hr)

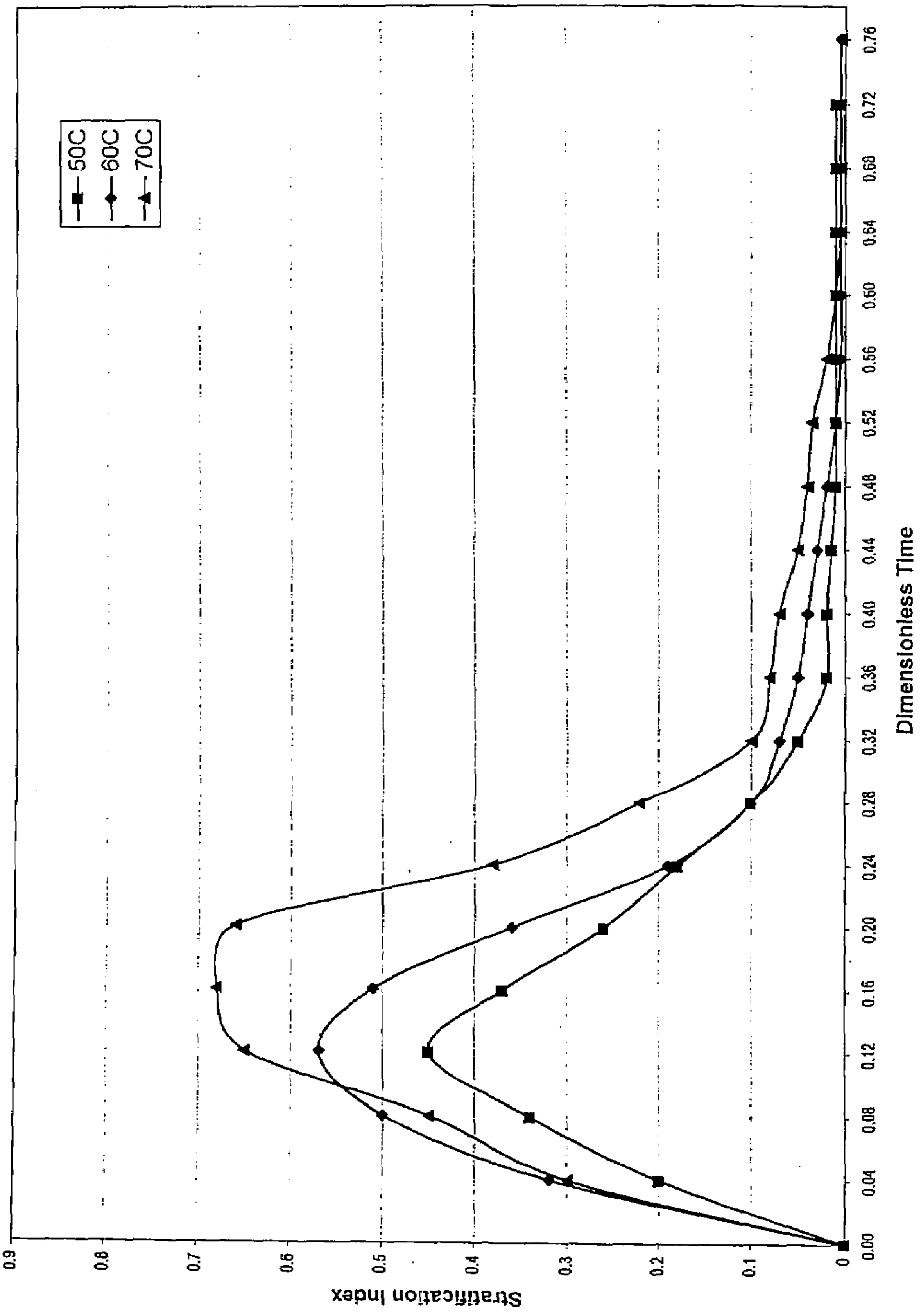

Fig. 3.5 Charging Mode
Variation of Stratification Index with Dimensionless Time for the Inlet 2
for DifferentTemperatures (Q=50 L/hr)

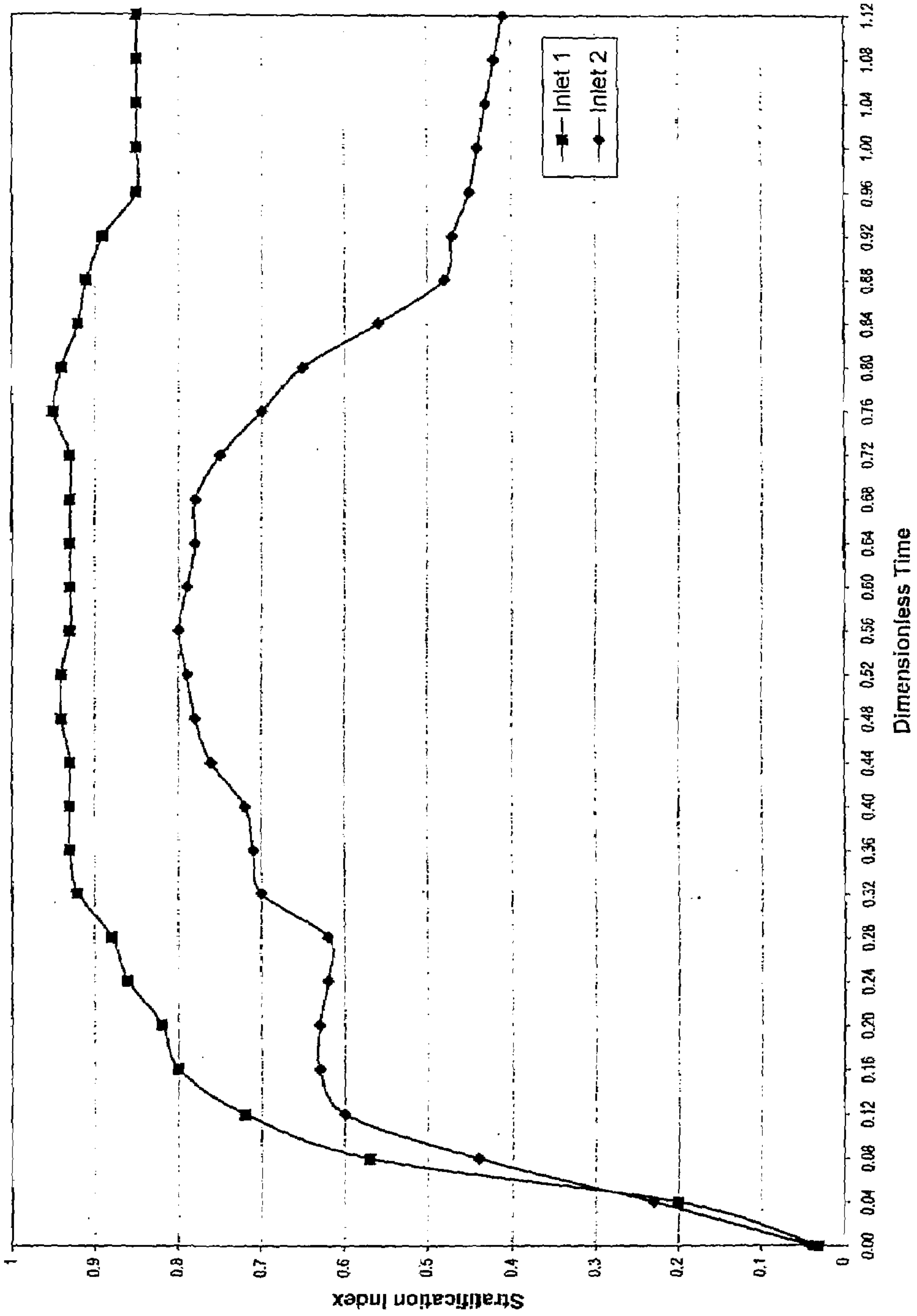

Fig. 3.6 Discharging Mode withoutCirculation

Variation of StratificationIndex with Dimensionless Time with Different Inlets Q=50 L/hr, T_{in}=50°C

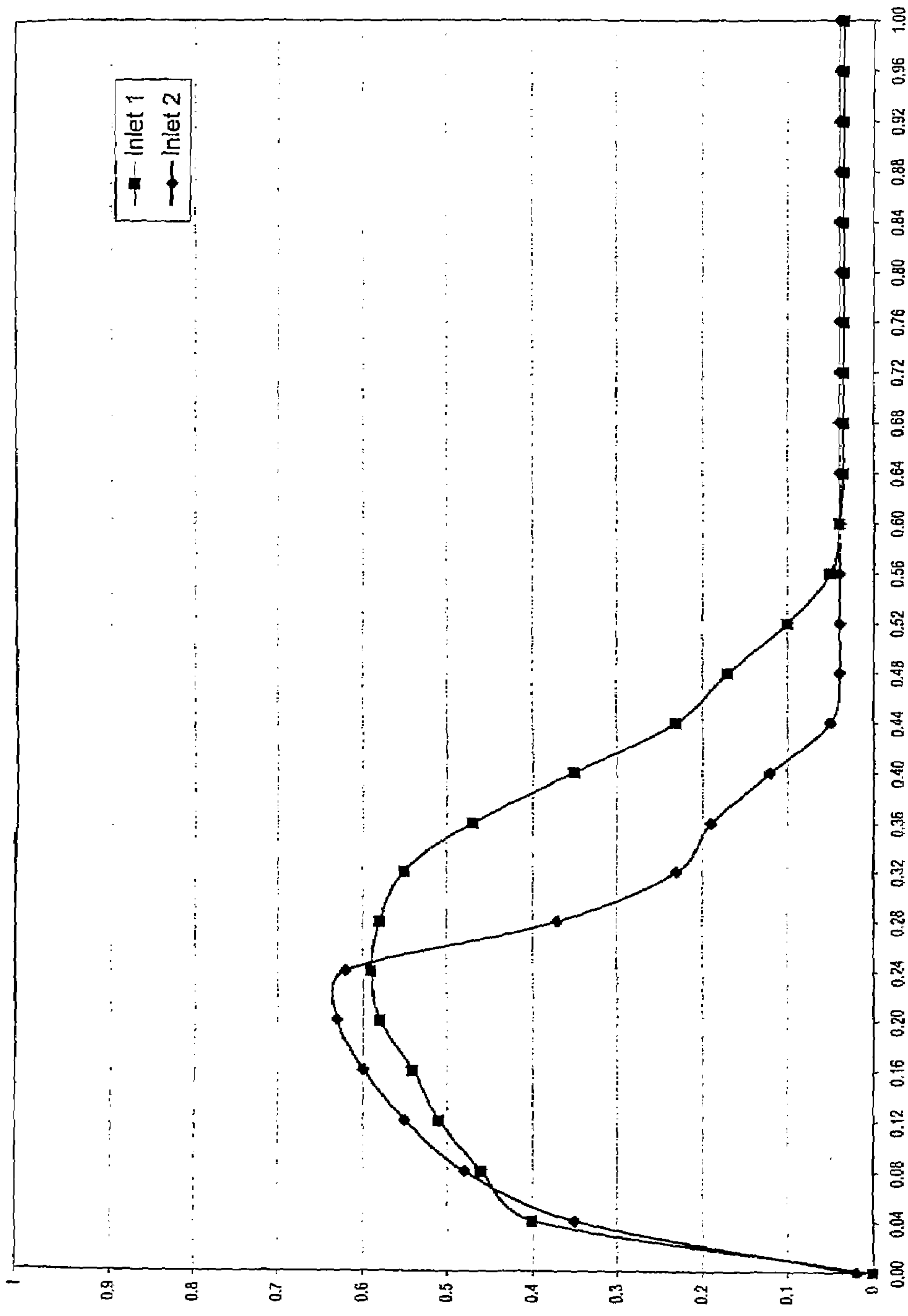

Fig.3.7 Discharging Mode with Circulation

Varation of StratificationIndex with Dimensionless Time with Different Inlets Q=50 L/hr, T_{in}=50°C