Chapter V

Results and Discussions

5.1 General

The mixing systems used were three capacities of continuous stirred mixer 6.3, 12.3 and 21.2 liters. Fully turbulence mixing which is commonly used in industrial mixing of low viscosity liquid was developed for the whole range of speed of the agitator. According to different size of the system, the hydrodynamic in each system must be kept similar. The scale-up method given in annexes was used to calculate the dimensionless group in order to keep the hydrodynamic in each system similar. Reynolds number was the main dimensionless group used to maintain dynamic similarity. The revolution of the impeller in each system were varied to achieve dynamic similarity as shown in Table 5.1. The revolution of the impeller in the smallest tank was 264.87, 441.57 and 618.27 rpm. respectively.

Volume of the tank (liters)	Revolution of the Impeller (rpm.)
6.3	618.27
	441.57
	264.87
12.3	494.62
	353.26
	211.90
21.2	412.18
	294.38
	176.58

Table 5.1 The revolution in each tank to achieve the hydrodynamic similarity

Another controlled factor in continuous system is residence time and the following table shows the inlet flow rate to achieve the required residence time in each system.

Volume of the tank (liters)	Residence Time (minutes)	Flow rate (cc/s)
6.3	30	3.49
	55	1.90
12.3	30	6.82
	55	3.72
	90	2.27
	125	1.64
21.2	30	11.78
	55	6.43
	90	3.93
	125	2.83

Table 5.2 The inlet flow rate in each tank to achieve the residence time similarity

Almost all experiments were carried out in continuous system and two experiments were carried out in batch system. All experiments were measured by conductivity method to determine the time the tracer remained in the system. The residence times were determined for the following conditions.

1. Size of the system: three sizes of the system, 6.3, 12.3 and 21.2 liters.
2. Type of impeller: three types of impeller, 6 bladed open turbine, 6 bladed disc turbine and 6 bladed 45 degree pitch turbine.
3. Calculated residence time: four calculated residence times, 30, 55, 90 and 125 minutes
4. Baffles: with and without baffles installation.

5. Position of the impeller: two positions of the impeller, 1/2 and 1/3 of liquid level from the bottom of the tank.
6. Revolution of the impeller: 264.87, 441.57 and 618.27 RPM in the smallest tank
7. The ratio of impeller diameter to tank diameter: 0.33 and 0.42
8. The direction of the 6 bladed 45 degree pitch turbine revolution: clockwise and counter clockwise.

The experiments were restricted to the range of 10^4 < Reynolds number < 10^6. At Reynolds number greater than 10^6, vortex will form in the center of the tank and may cause air to dissolve in the system. In the range of $10 < Re < 10^4$, the system is in the transition zone, the velocity difference between the liquid and the impeller is so large that the centrifugal effect is predominant. The operating condition should be selected so that the system is in the turbulent zone to remove this effect.

5.2 Impeller Revolution Calibration

The impeller revolution is calibrated with the voltage input in the experimental range. The calibration curve is shown in Figure 5.1.

From Fig.5.1, it is found that the relation between the revolution of the impeller and the voltage input is linear. This relation can be expressed by the following equation.

$$\text{Revolution (RPM)} = 4.754 \times (\text{Voltage Input (V)}) - 27.252 \qquad (5\text{-}1)$$

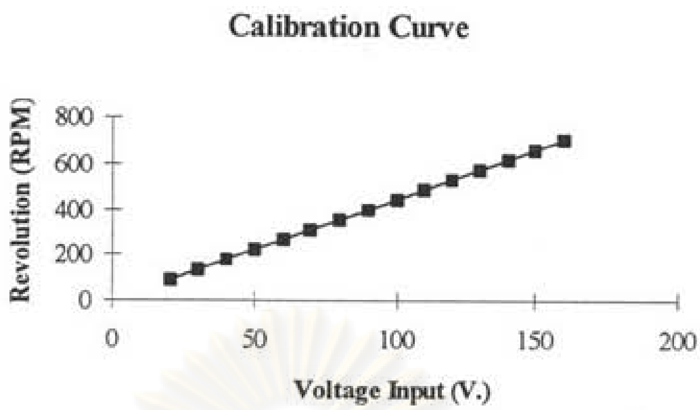


Figure 5.1 Calibration curve between impeller revolution versus voltage input.

5.3 Conductivity Calibration

The concentration is calibrated with the conductivity in the experimental range. The calibration curve is shown in Figure 5.2.

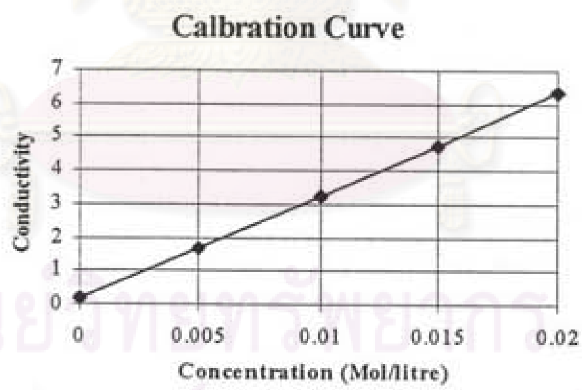


Figure 5.2 Calibration curve between conductivity versus concentration.

From Figure 5.2, it is found that the relation between the concentration and the conductivity in the experimental range is linear. This relation can be expressed by the following equation.

$$\text{Conductivity (S/cm)} = 307.2 \times \text{Concentration (Mole/liter)} + 0.16 \qquad (5\text{-}2)$$

5.4 Discussion on Batch Mixing System and Continuous Mixing System

Batch and continuous mixing system were set up in order to compare the performance of the systems. In continuous stirred system, the inlet flow rate was set very slow in order to make the continuous system similar to the batch system as much as possible. From Fig. 5.3, it is found that the concentration in batch system during the first period increased sharply and then it swung like a sine curve until it reached the final concentration. In continuous stirred vessel, no swinging occurred during the first period but the slope increased sharply. When it reached a peak, it was constant for a while and then the slope decreased slowly until it reached the initial concentration. It is found that the peak of continuous stirred system was less than the final value of the batch stirred system because the tracer could exit as soon as it was injected so the peak of the continuous system was always less than the final concentration of the batch system.

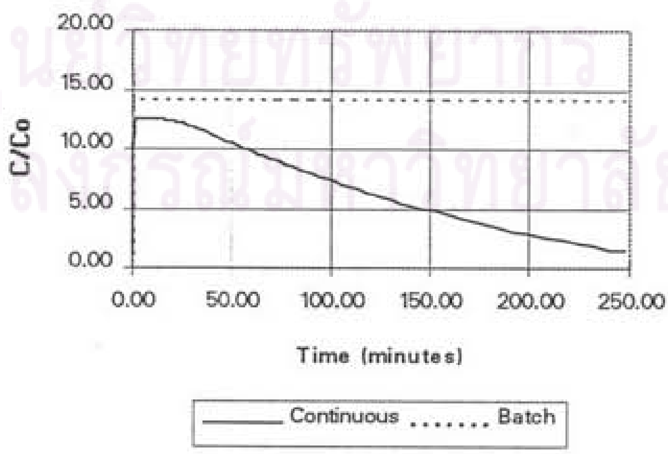


Figure 5.3 Comparison chart between batch and continuous mixing system

5.5 The Parameter Effecting the Continuous Stirred Vessel

From the results, there were two interesting parameters to analyze in continuous stirred vessels, residence time and mixing time.

5.5.1 The Parameter Effecting the Residence Time in the Continuous Stirred Vessel

In the determination of the residence time, the tracer was injected at the entrance to the vessel. The conductivity at the exit was recorded at a fixed time interval until the conductivity decreased to the initial concentration. The data were normalized and the residence time was calculated in the given annexes. From the experimental residence time, many parameters effecting the continuous stirred vessel were found as follows:

5.5.1.1 Effect of the Rotational Speed of the Impeller

For the same type of impellers and tank configuration, the required residence time was longer as rotational speed of impeller was increased as shown in Table 5.3. From Fig.5.4 through Fig.5.12, the peak of high rotational speed of impeller was higher than the peak of low rotational speed of impeller. The decreasing slope of higher speed was steeper. It could be explained that high rotational speed sent a large amount of the tracer to the stagnant zone, near the bottom of the tank and caused the system to reach the homogeneous state more quickly so the tracer left the system more slowly.

5.5.1.2 Effect of the Inlet Flow Rate

In all experiments (Fig.5.14 - 5.18), the residence time in the system with high inlet flow rate was shorter than the residence time in the system with low inlet flow rate. The experimental residence time is less than the mean residence time. At constant volume, high inlet flow rate caused the tracer to exit more quickly than at low inlet flow rate, thereby resulting in a shorter residence time.

5.5.1.3 Effect of the Impeller Position

In almost all experiments of the straight blade impeller with disc (Fig.5.19-5.24), the required residence time of the impeller position set at 1/3 of tank diameter above tank bottom was shorter than the required residence time of the impeller position set at 1/2 of tank diameter above tank bottom. From Komolgoroff's theory of energy dissipation [10] which stated that there was a transfer of kinetic energy down the scale from larger eddies to smaller eddies and the large eddies had large velocity fluctuations and large kinetic energy. When the large eddies impacted tank wall, it caused another eddies in the opposite direction due to kinetic energy transfer. The new eddies caused more turbulence in the system. Therefore, the position of the radial flow impeller nearer to the bottom caused a more turbulent current near the bottom thereby entraining the tracer up to the exit at the top very rapidly. But in almost all experiments using pitch blade impeller rotating in the direction that caused the current to flow up to the liquid surface, the required residence time of the impeller position set at 1/2 of tank diameter above tank bottom was shorter than the required residence time of the impeller position set at 1/3 of tank diameter above tank bottom. It may be possible that the axial flow impeller could lead the tracer direct to the surface and exit more quickly.

5.5.1.4 Effect of the Direction of the Impeller Rotation

The direction of the impeller rotation was varied using only 45° pitch bladed impeller. In almost all experiments (Fig.5.25-5.30), the impeller position was set at 1/3 of tank diameter above tank bottom, the required residence time of rotation in counter clockwise direction*, was longer than in clockwise direction. It may be possible that the rotation in the clockwise direction conducted the tracer directly in the downward direction causing it to hit the bottom of the vessel and creating more turbulent according to Komolgoroff's theory [10] and thereby causing the tracer to exit from the system more rapidly than in the opposite direction.

5.5.1.5 Effect of Tank Size

From the experiments (Fig.5.31-5.36), the residence time in small tank was shorter than large tank. It could be explained that there are more circulation currents in larger tank than in smaller tank so more tracer was trapped in the circulation current. The more the tracer is in the circulation current, the longer is the residence time in the mixing system.

5.5.1.6 Effect of Impeller Type

From Fig.5.37 through Fig.5.42, the impeller type are compared as follows:

* Rotation in counter clockwise means rotation in the direction that cause the current to flow up to the liquid surface and Rotation in clockwise means rotation in the direction that cause the current to flow down to the tank bottom.

5.5.1.6.1 Straight Bladed Impeller

In almost all experiments, the residence time in the system using 6 bladed disc turbine was shorter than the system using paddle. It could be described by Marr's model (Eq.3-2). From Marr's model, the residence time is a function of the internal flow rate and the internal flow rate is a function of the Reynolds' number and the discharge flow rate. The discharge flow rate depends on the geometry of the impeller. It was found that the disc in 6 bladed disc turbine separated the current in two portions, upper and lower portions, and the impeller with disc had a pumping characteristic (impeller pumping plus the total induced flow) so the impeller with disc caused more discharge flow rate. The more the discharge flow rate, the shorter is the residence time.

5.5.1.6.2 Straight and Pitch Bladed Impeller

In almost all experiments, the residence time in the system with straight bladed impeller was shorter than the system with pitch bladed impeller. It could be explained by Marr's model (Eq.3-2) that straight blade caused more violent current than pitch blade at the same rotation speed because the blade of straight bladed impeller contacted the liquid more directly than the blade of pitch bladed impeller. From Table 3.4, the discharge flow rate from straight bladed impeller was greater than pitch bladed impeller so the residence time was shorter.

5.5.1.7 Effect of Impeller Diameter

In all experiments (Fig.5.43-5.44), the residence time in the system with larger impeller diameter is shorter than the system with smaller impeller. It could be explained that the larger impeller could sweep more current than the smaller impeller and it caused the tracer in the system to exit more quickly than the smaller impeller.

5.5.1.8 Effect of Baffles

In this experimental condition, the system without baffles could not be set at high impeller rotation due to vortex which caused the swinging in the measurement. However, the system without baffles was set at low rotation speed of the impeller and it was found that there is no difference in residence time. From the results (Fig.5.45), baffles are not required in the laminar flow region.

5.5.2 The Parameter Effecting the Mixing Time in the Continuous Stirred Vessel

In the determination of the mixing time, the tracer was injected at the entrance and the concentration of the tracer was measured at two points, at the impeller level and at the exit. The concentration was recorded until measurement at both points are the same. The data was normalized and the mixing time was calculated the time from tracer injection to the concentration difference between two points was less than the acceptable value. From the experimental results (Table 5.4), the parameters effecting the mixing time in continuous stirred vessel were found as follows:

5.5.2.1 Effect of Rotational Speed of Impeller

For the same type of impeller and tank configuration (Fig.5.76), the required mixing time was shorter as rotational speed of impeller was increased as shown in Table 5.3. This is caused by more convective mass transfer occurring when the rotational speed of impeller is increased.

5.5.2.2 Effect of Impeller Type

In impeller type comparison (Fig.5.77), Nagata's mixing time model (Eq.3-1) could be used to explain the results. The more the discharge flow rate, the shorter is the mixing time.

5.5.2.2.1 Straight Bladed Impeller Compare

From experiments, comparing between straight bladed impeller with disc and without disc, it is found that the mixing time in the system using flat bladed disc impeller was shorter than the mixing time in the system using bladed impeller without disc. It could be decribed that the disc separated the system into many small mixing zones and the pumping characteristic of the impeller with disc caused more discharge flow rate so the time to achieve complete mixing in small mixing region was shorter than the system without disc.

5.5.2.2.2 Straight and Pitch Bladed Impeller

For the same condition and tank configuration, the system with straight bladed impeller has shorter mixing time than the system with pitch bladed impeller. It was noticed that there was disturbance in the first period in the mixing system using pitch bladed impeller. From table 3.4, the discharge flow rate from straight bladed impeller was greater than pitch bladed impeller so the mixing time was shorter. It could be concluded that the impeller which generated radial flow could achieve complete mixing faster than the impeller which generated axial flow.

5.5.2.3 Effect of Diameter of the Impeller

In all experiments (Fig.5.78), the mixing time in the system with larger impeller is shorter than the mixing time in the system with smaller impeller. It was noticed that there was disturbance in the first period in the mixing system using larger impeller. The system with larger impeller diameter caused more convective mass transfer when its rotational speed was equal to the system with smaller impeller.

5.5.2.4 Effect of the Inlet Flow Rate

In all experiments (Fig.5.779), the mixing time in the system with high inlet flow rate was shorter than the system with low inlet flow rate. The inlet flow contributed to making the system more turbulent than the batch system which is a non-flow system so the higher inlet flow rate caused the system to mix completely faster than the slow inlet flow rate.

5.5.2.5 Effect of Direction of the Impeller

The direction of the impeller rotation was varied using only 45° pitch blade at 1/3 of the tank diameter from the tank bottom. In almost all experiments (Fig.5.80), the required mixing time of the counter clockwise direction of the impeller rotation was shorter than the clockwise direction of the impeller rotation. It could be explained that the rotation in the counter-clockwise direction conducted the tracer to the liquid surface more directly and rapidly than rotating in the opposite direction to overpass the exit so it could not leave the system rapidly, so it spread over the system more rapidly, resulting in shorter mixing time and longer residence time.

5.6 Conclusion

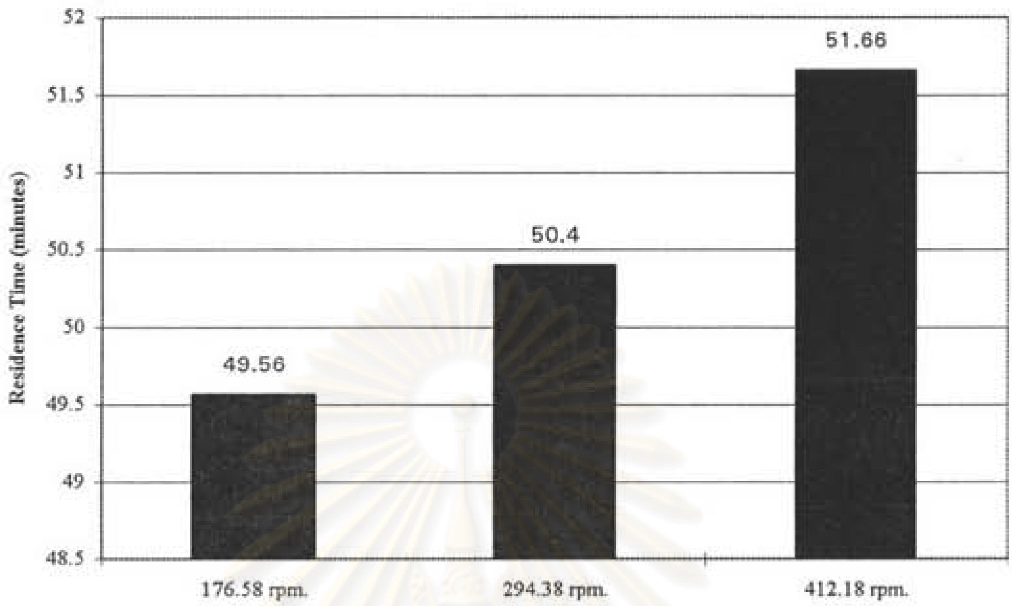
In order to select the continuous stirred vessel, both residence time and mixing time played important roles in the selection. Good mixing system should have a small mixing time as possible and the residence time should not be longer than the mean residence time because the mean residence time is the theoretical value that the time the system holding the tracer calculated from the inlet flow rate. If experimental residence time is greater than the mean residence time, the tracer is circulated and trapped in the dead region of the system so product yield will be longer than expected.

Tank Diameter (cm.)	Type of the Impeller	Mean Residence Time (min.)	Position					
			1/3			1/2		
			Rotational Speed (RPM)					
			176.58	294.38	412.18	176.58	294.38	412.18
30	Turbine	30	17.55	17.84	17.98	18.09	18.11	18.19
		55	27.87	28.14	28.36	31.50	32.25	32.32
		90	49.56	50.40	51.66	50.47	52.25	53.29
		125	70.08	70.31	70.62	74.15	75.05	75.06
	Paddle	30	18.46	18.48	18.54	18.08	18.96	19.07
		55	32.95	33.05	33.23	31.93	32.69	32.87
		90	50.84	53.27	53.76	52.59	53.66	55.03
		125	74.63	75.14	77.81	74.09	72.34	73.47
	45° Pitch CCW	30	19.11	19.32	19.68	18.73	18.89	-
		55	35.84	37.73	-	31.23	33.04	-
		90	-	62.41	-	-	-	-
		125	77.66	-	-	-	-	-
	45° Pitch CW	30	18.94	19.23	19.55	-	-	-
		55	35.91	-	37.98	-	-	-
		90	-	55.73	-	-	-	-
		125	77.24	-	-	-	-	-
Tank Diameter (cm.)	Type of the Impeller	Mean Residence Time (min.)	Rotational Speed (RPM)					
			211.90	353.26	494.62	211.90	353.26	494.62
25	Turbine	30	15.65	16.22	16.47	16.02	16.26	16.62
		55	26.43	26.69	26.85	-	-	-
		90	47.34	47.42	47.53	-	-	-
		125	67.08	70.04	69.61	-	-	-
	Paddle	30	16.11	16.32	16.46	16.06	17.04	16.81
		55	28.43	28.59	28.64	-	-	-
	45° Pitch	30	15.47	16.01	16.38	15.23	15.60	-
Tank Diameter (cm.)	Type of the Impeller	Mean Residence Time (min.)	Rotational Speed (RPM)					
			264.87	441.57	618.27			
20	Turbine	30	15.39	15.60	15.81			
		55	26.19	26.73	26.82			
	Paddle	30	15.12	16.45	16.50			
	45° Pitch	30	15.93	16.53	18.28			
	Big Turbine	30	15.29	15.34	-			
	Big Paddle	30	16.97	17.35	15.81			

Table 5.3 The residence times at any conditions

Residence Time (min.	Type of Impeller	Ratio of Position to Liq. H		
		1/3		
		Revolution (RPM)		
		264.87	441.57	618.27
30	Standard Turbine	105	102	99
	Bigger Turbine	85	80	-
	Paddle	110	105	115
	45° Pitch CCW	180	150	140
	45° Pitch CW	250	180	150
55	Standard Turbine	270	200	140
	Bigger Turbine	210	130	-
	Paddle	290	200	140
	45° Pitch CCW	300	210	170
	45° Pitch CW	390	270	220
15	Standard Turbine	54	42	42
	Paddle	60	50	44
	45° Pitch	100	57	48

Table 5.4 The mixing times at any Conditions



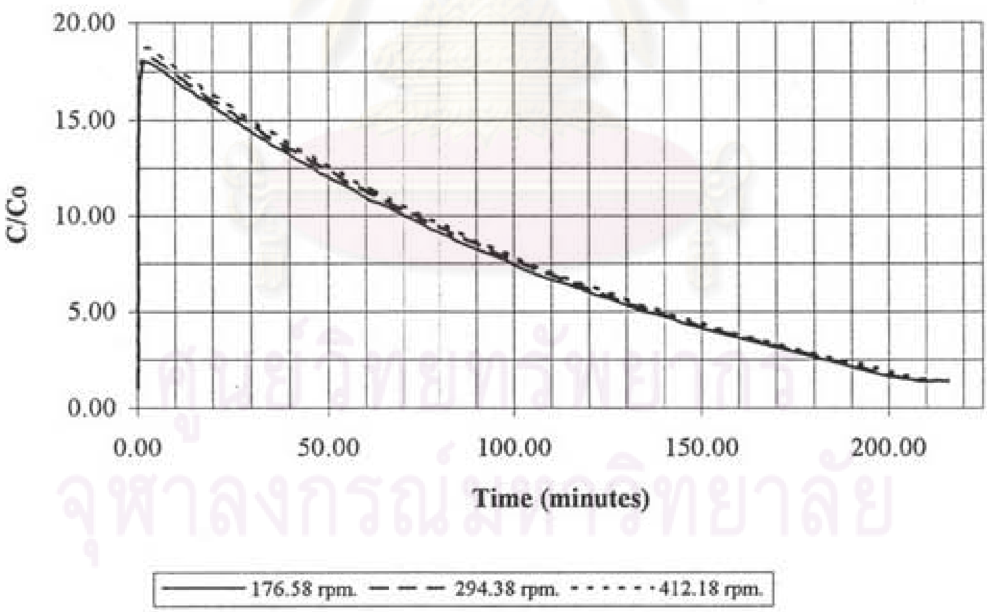
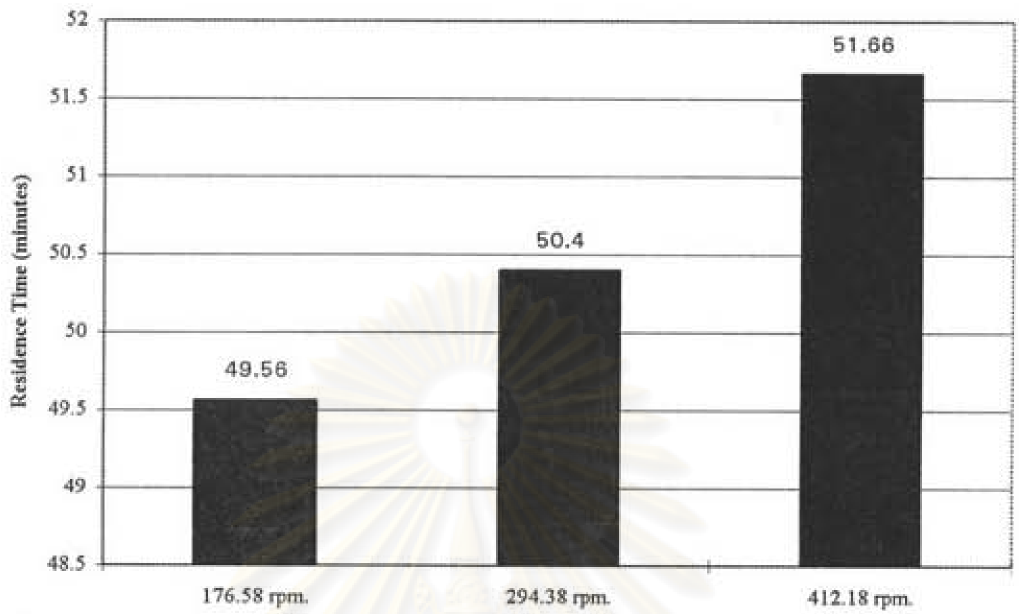


Figure 5.4 Comparison between the rotational speed of turbine at 1/3 of the tank diameter above the bottom in 30 cm tank diameter (residence time 125 minutes)



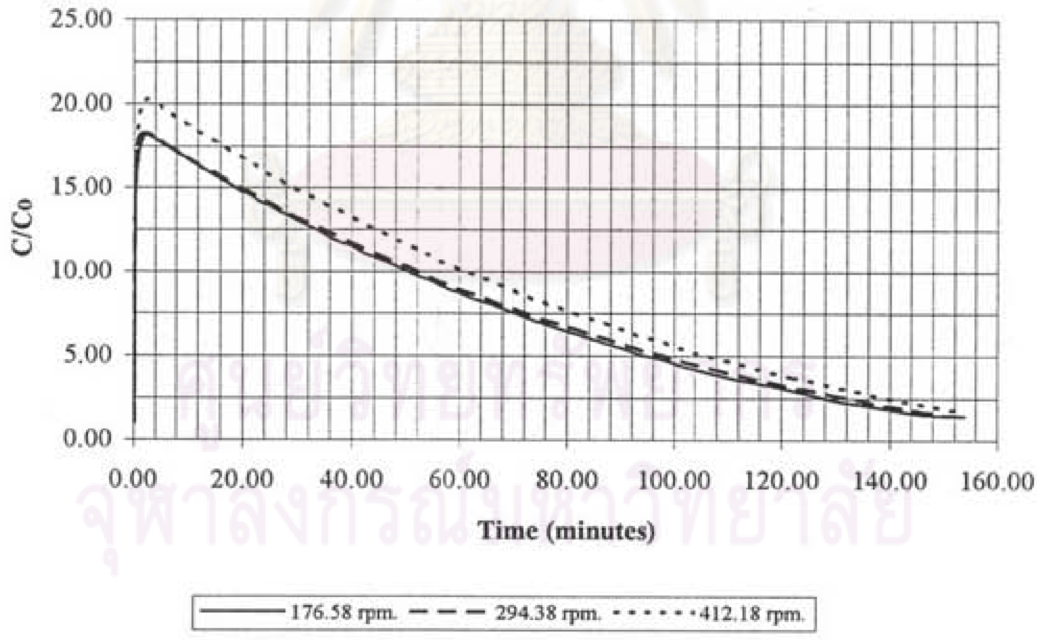
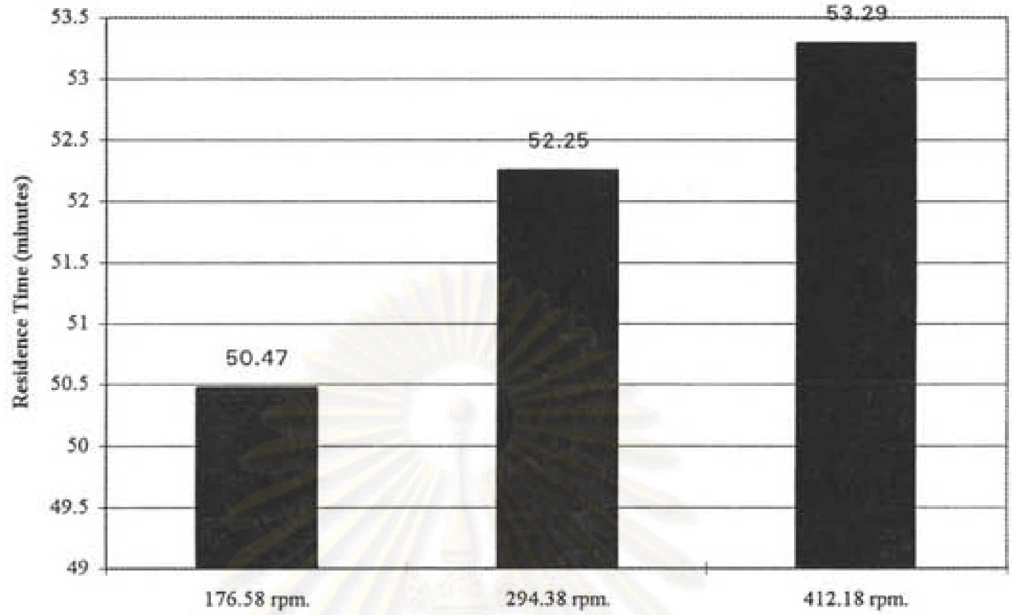


Figure 5.5 Comparison between the rotational speed of turbine at 1/3 of the tank diameter above the bottom in 30 cm tank diameter (residence time 90 minutes)



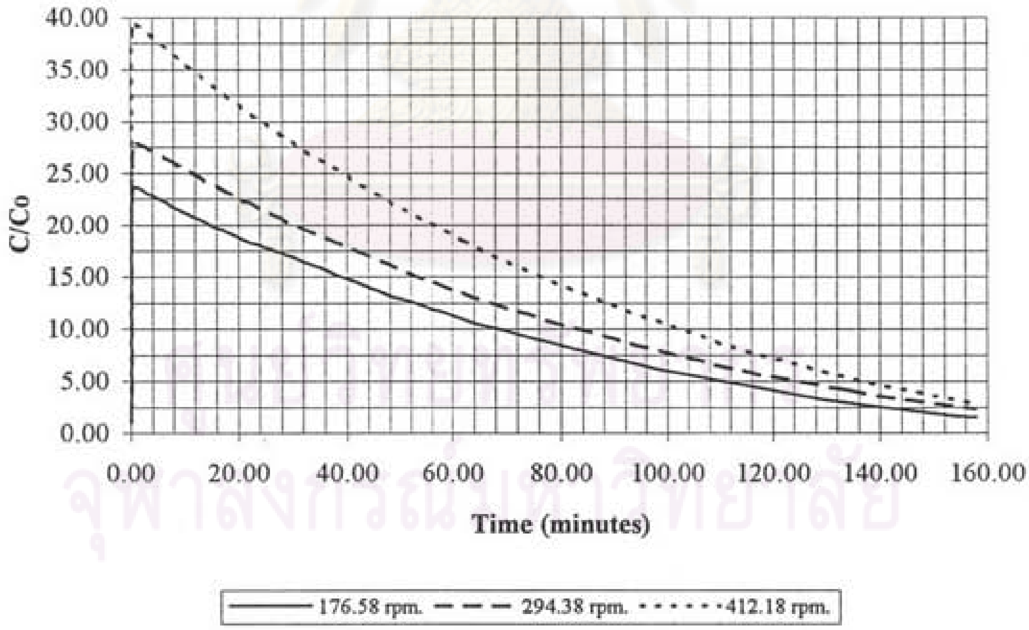
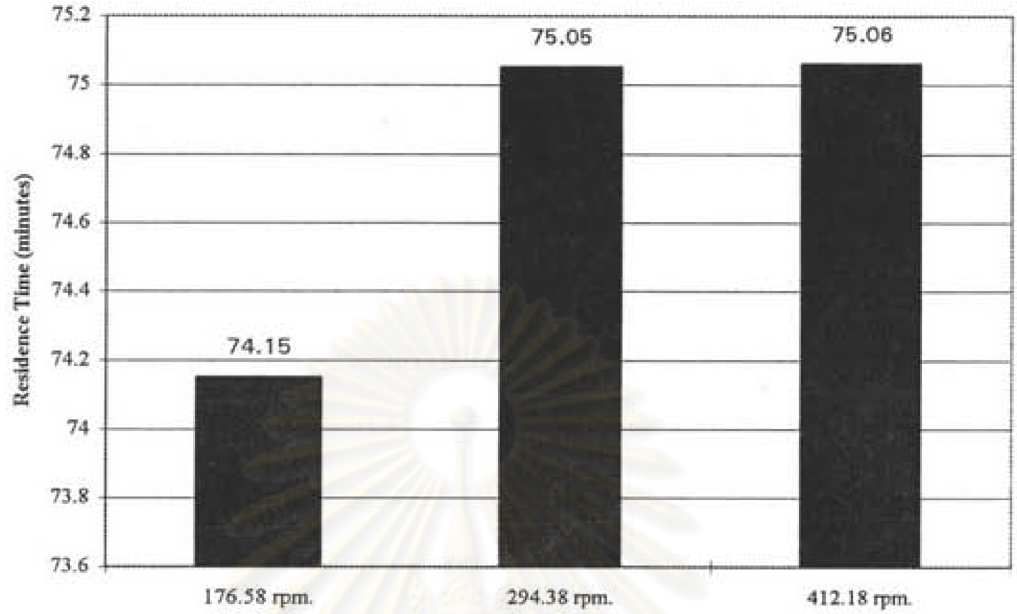


Figure 5.6 Comparison between the rotational speed of turbine at 1/2 of the tank diameter above the bottom in 30 cm tank diameter (residence time 90 minutes)



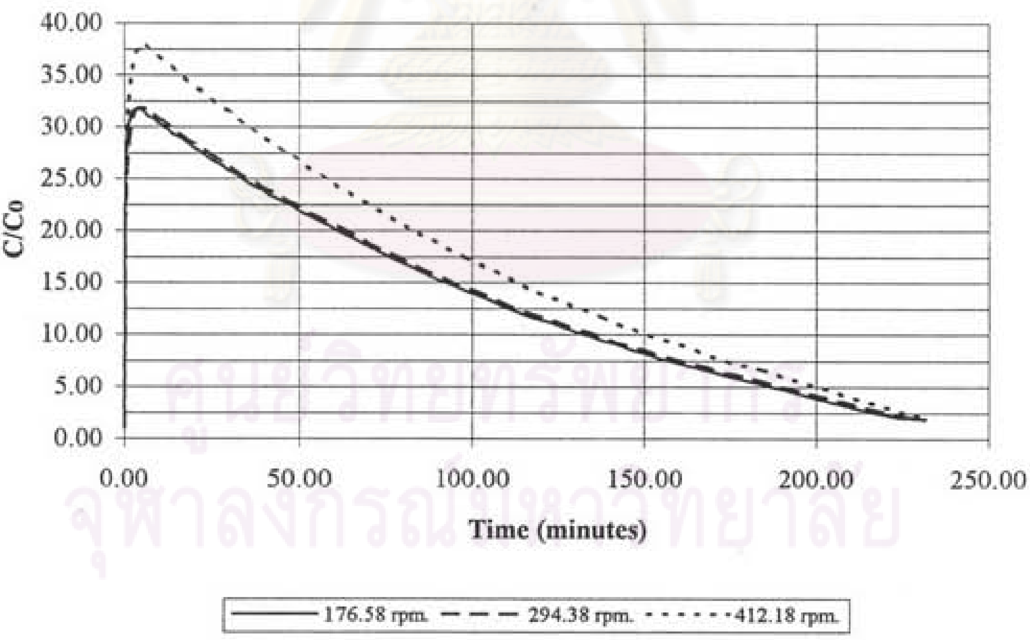
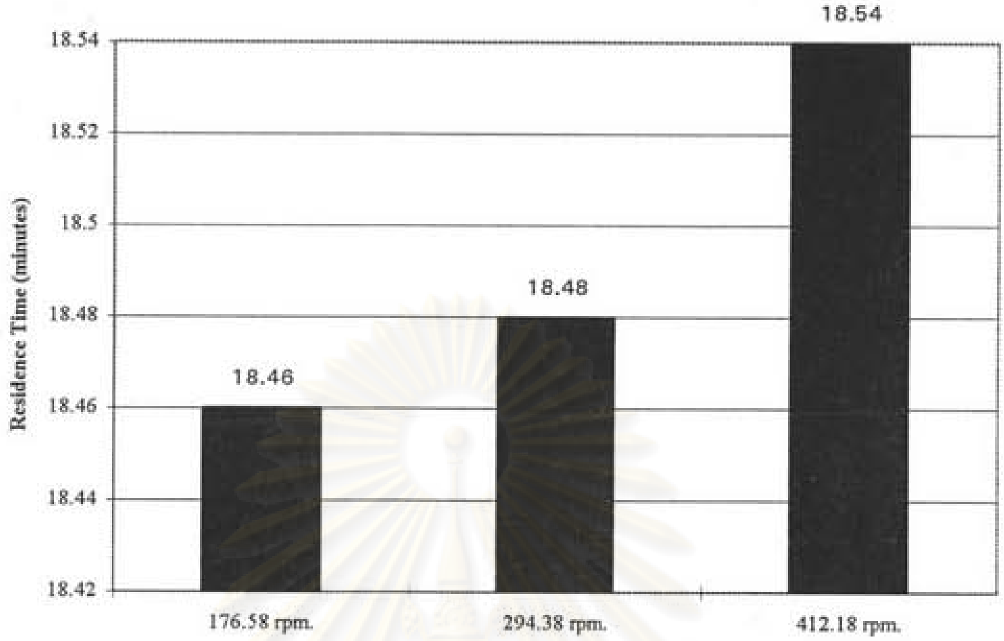


Figure 5.7 Comparison between the rotational speed of turbine at 1/2 of the tank diameter above the bottom in 30 cm tank diameter (residence time 125 minutes)



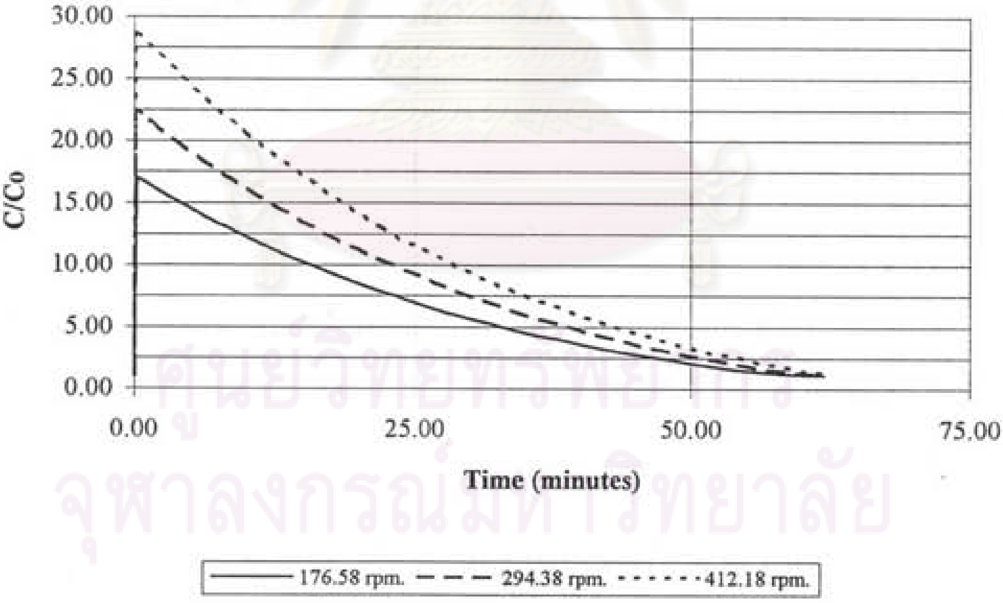
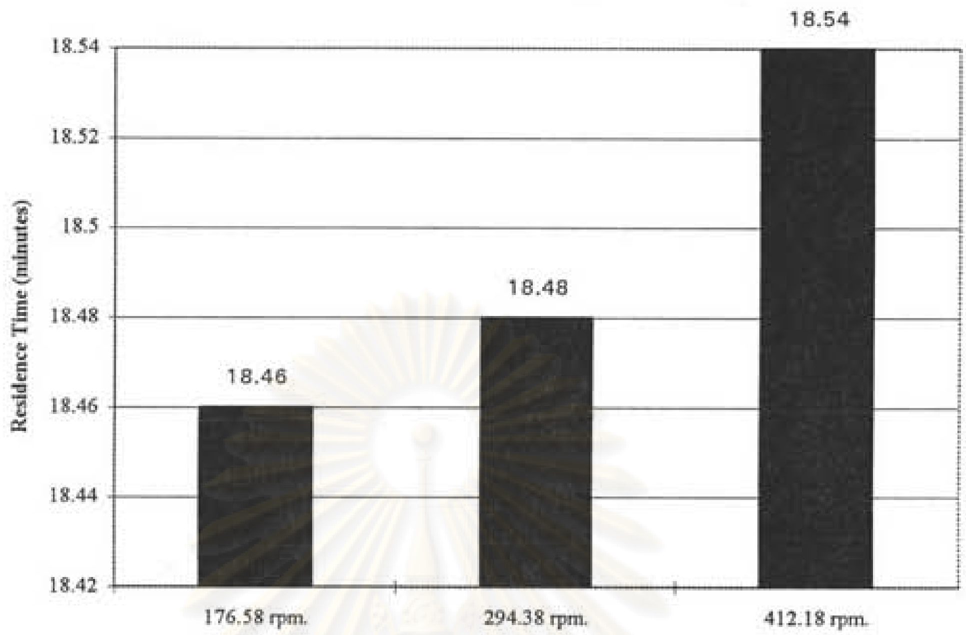


Figure 5.8 Comparison between the rotational speed of turbine at 1/2 of the tank diameter above the bottom in 30 cm tank diameter (residence time 30 minutes)



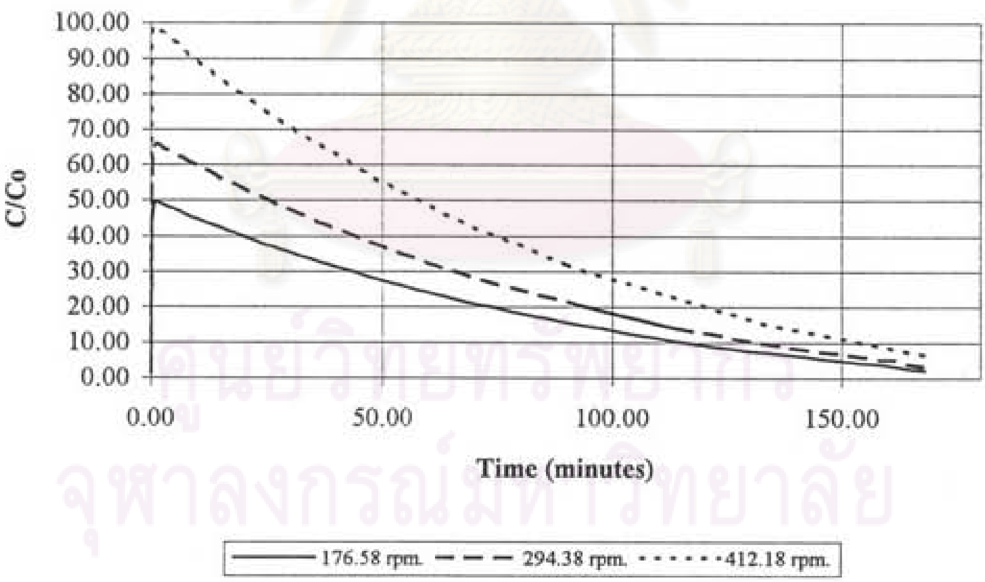
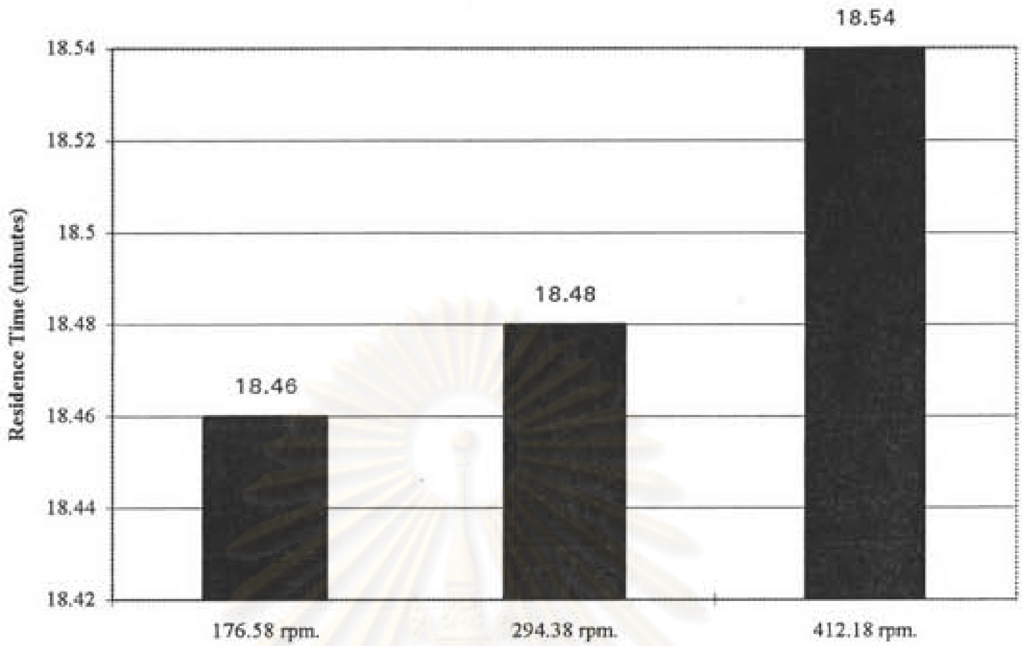


Figure 5.9 Comparison between the rotational speed of paddle at 1/2 of the tank diameter above the bottom in 30 cm tank diameter (residence time 90 minutes)



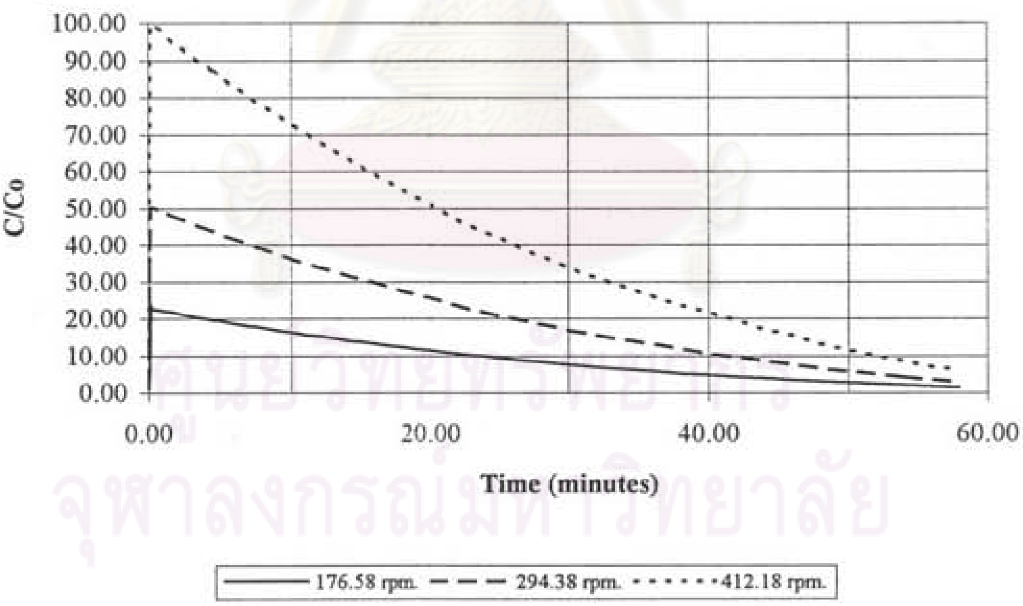
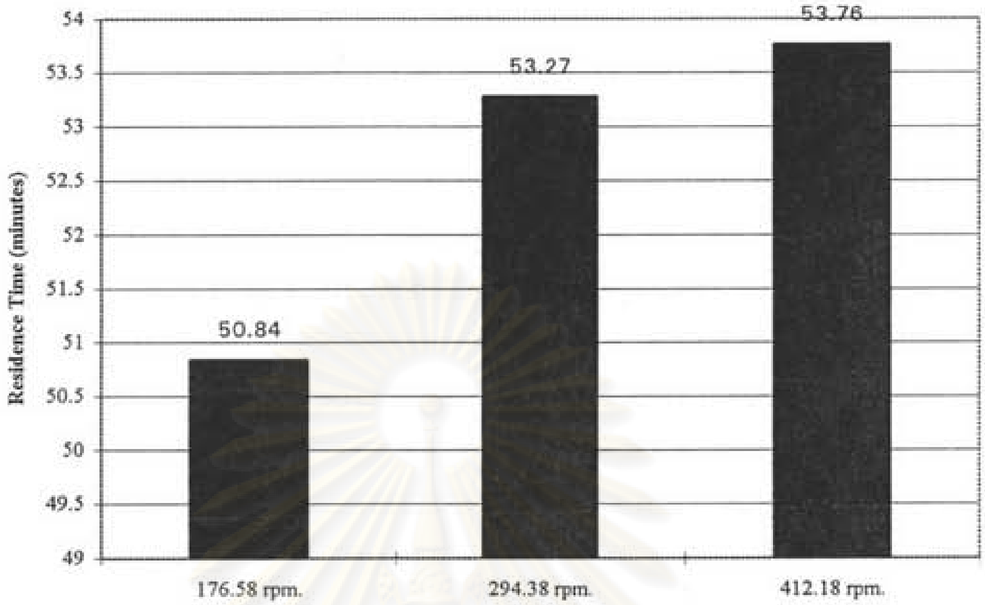


Figure 5.10 Comparison between the rotational speed of paddle at 1/3 of the tank diameter above the bottom in 30 cm tank diameter (residence time 30 minutes)



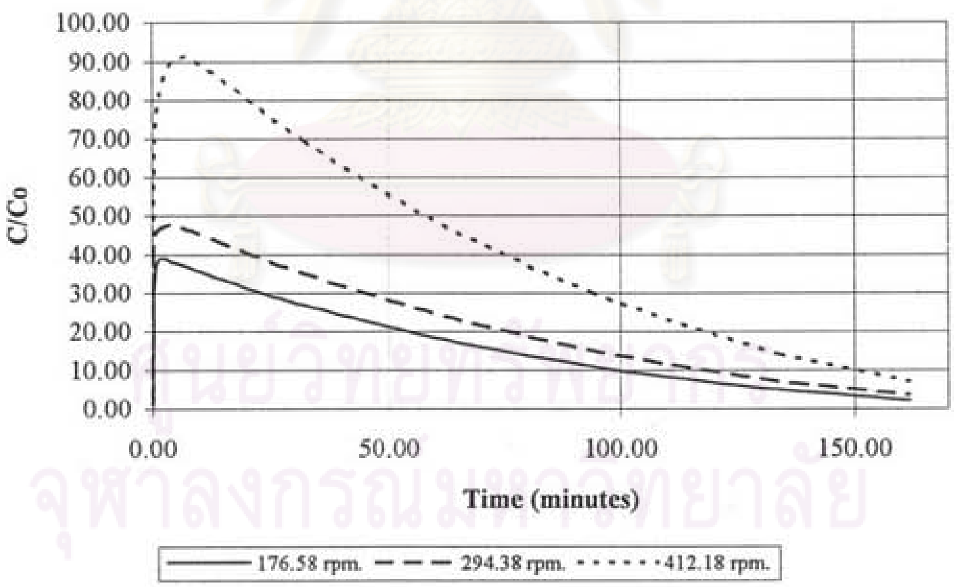
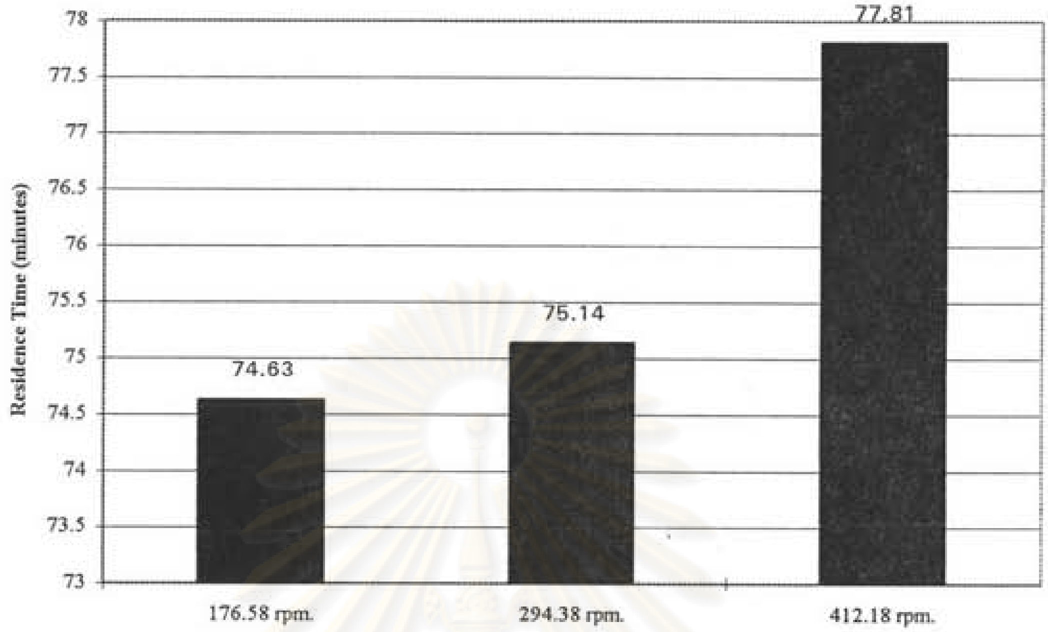


Figure 5.11 Comparison between the rotational speed of paddle at 1/3 of the tank diameter above the bottom in 30 cm tank diameter (residence time 90 minutes)



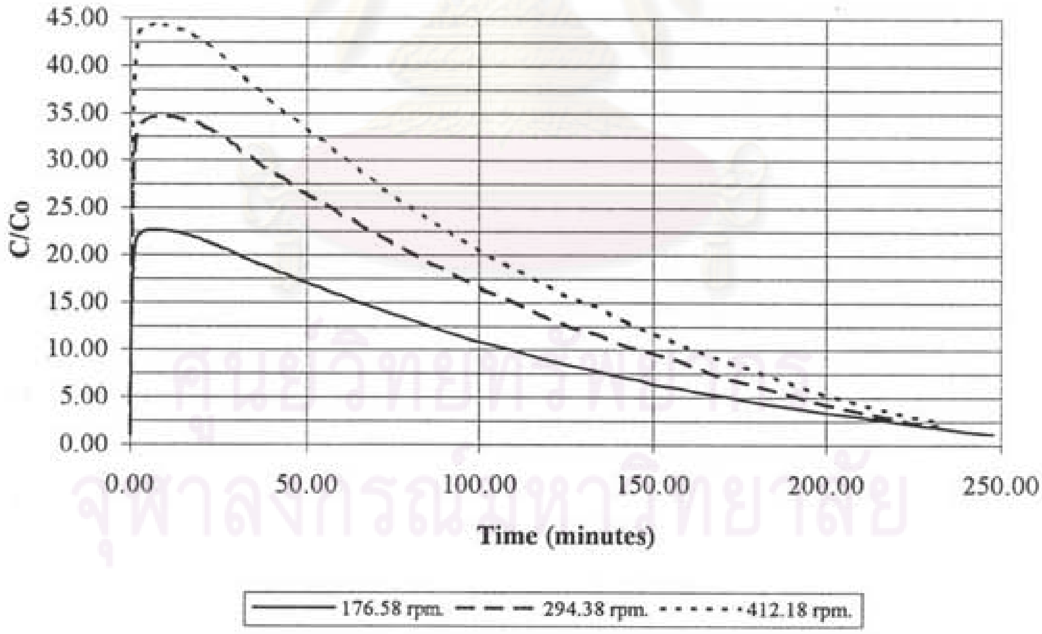
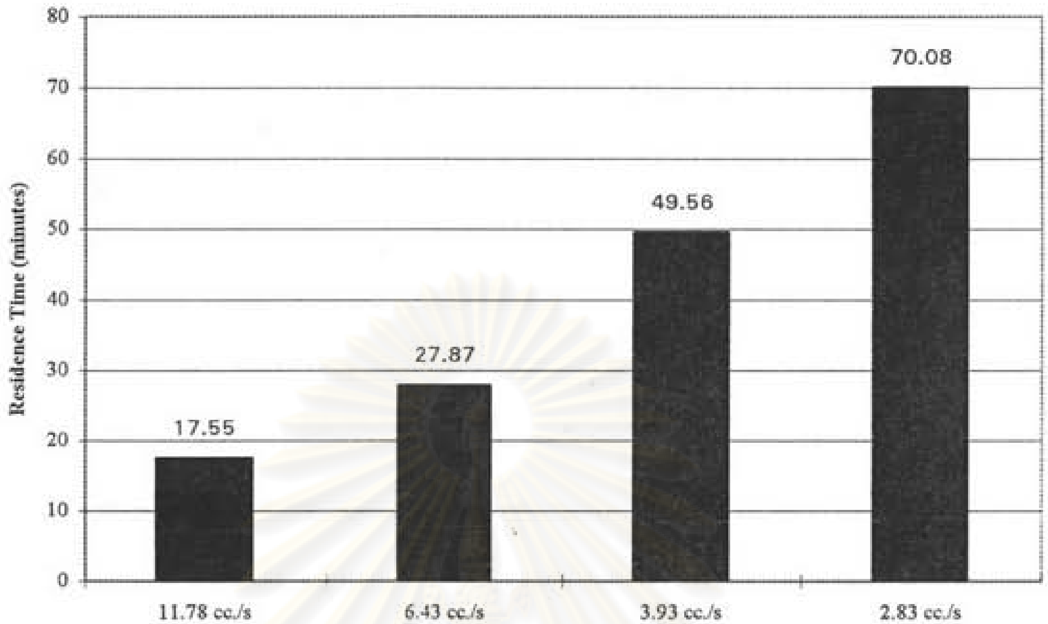


Figure 5.12 Comparison between the rotational speed of paddle at 1/3 of the tank diameter above the bottom in 30 cm tank diameter (residence time 125 minutes)



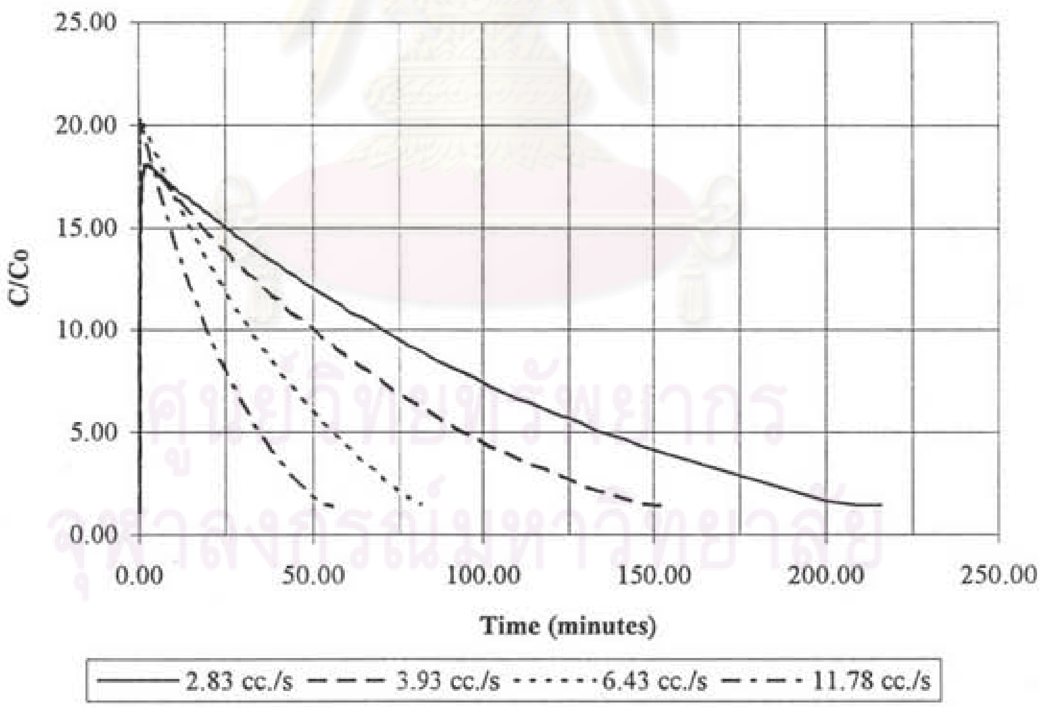
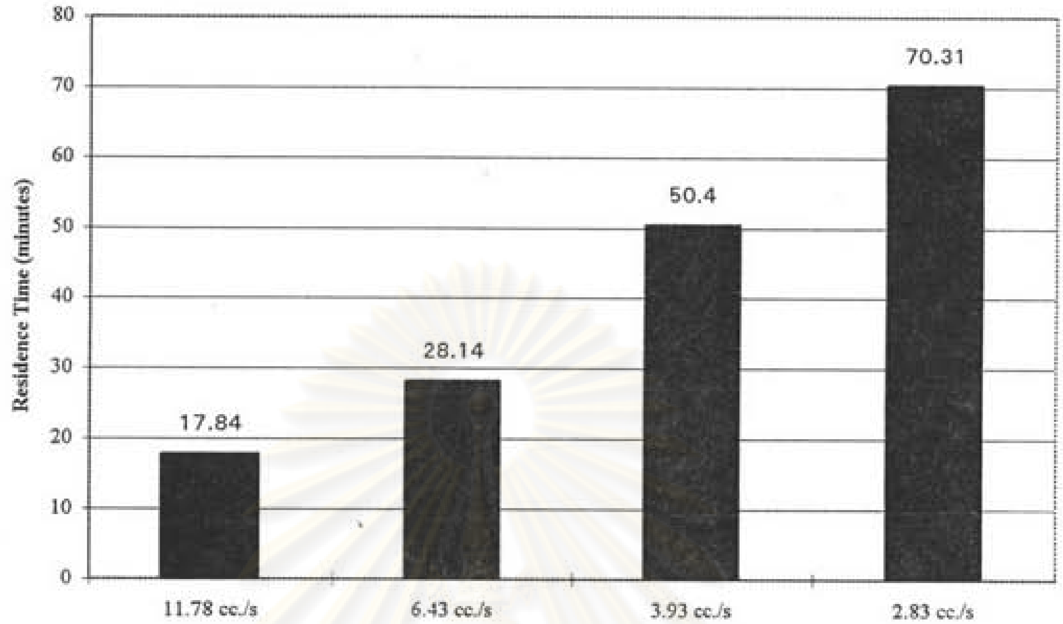


Figure 5.13 Comparison between the inlet flow rate of turbine at 1/3 of the tank diameter above the bottom with speed 176.58 rpm. in 30 cm tank diameter



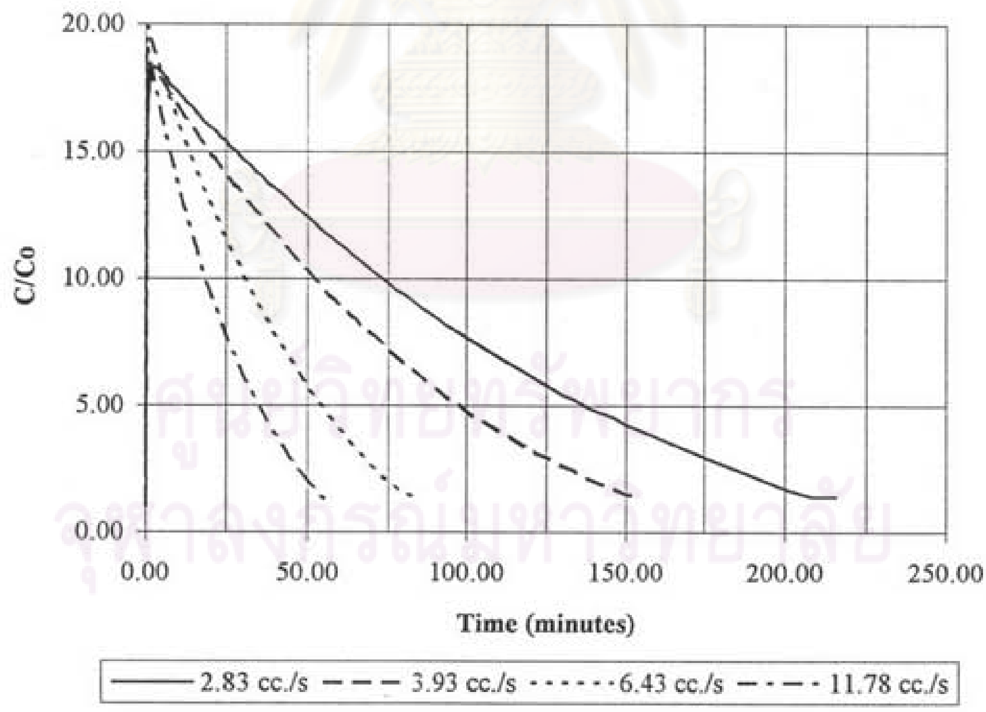
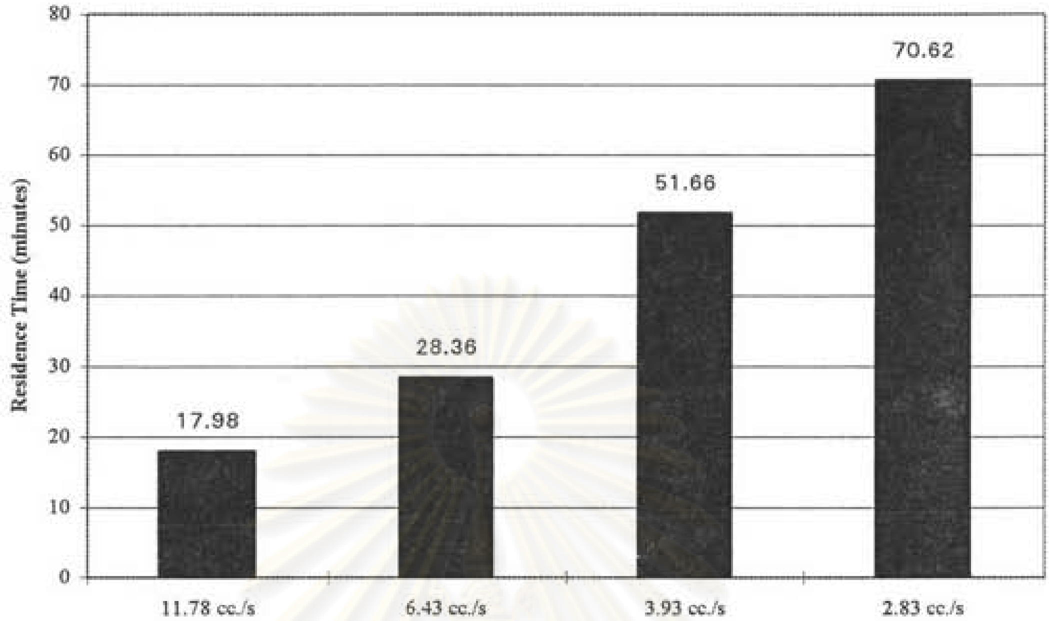


Figure 5.14 Comparison between the inlet flow rate of turbine at 1/3 of the tank diameter above the bottom with speed 294.38 rpm. in 30 cm tank diameter



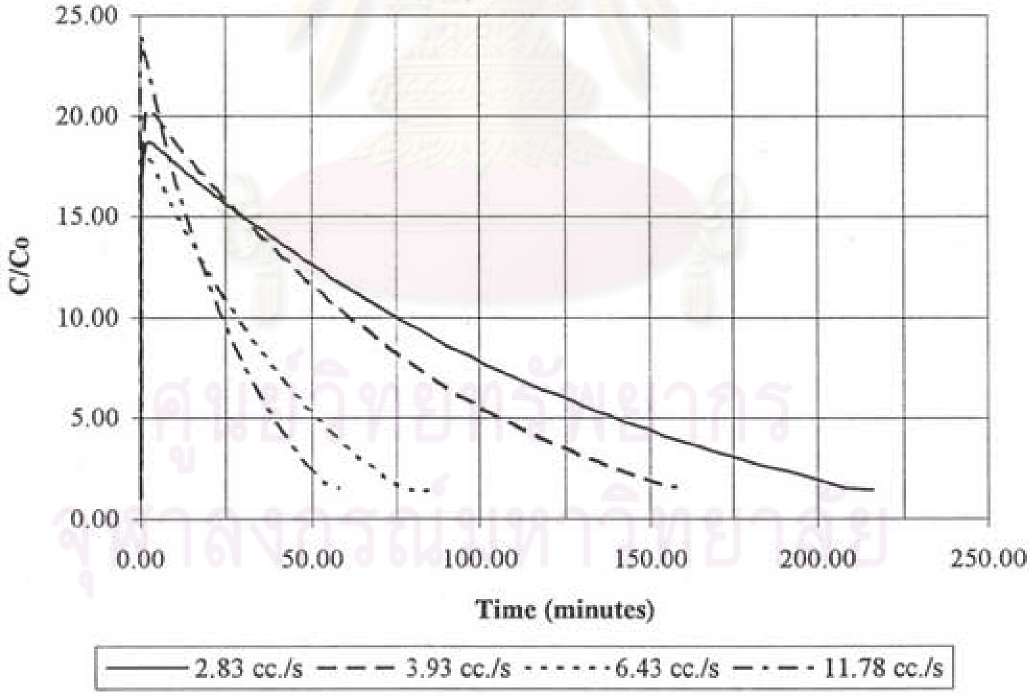
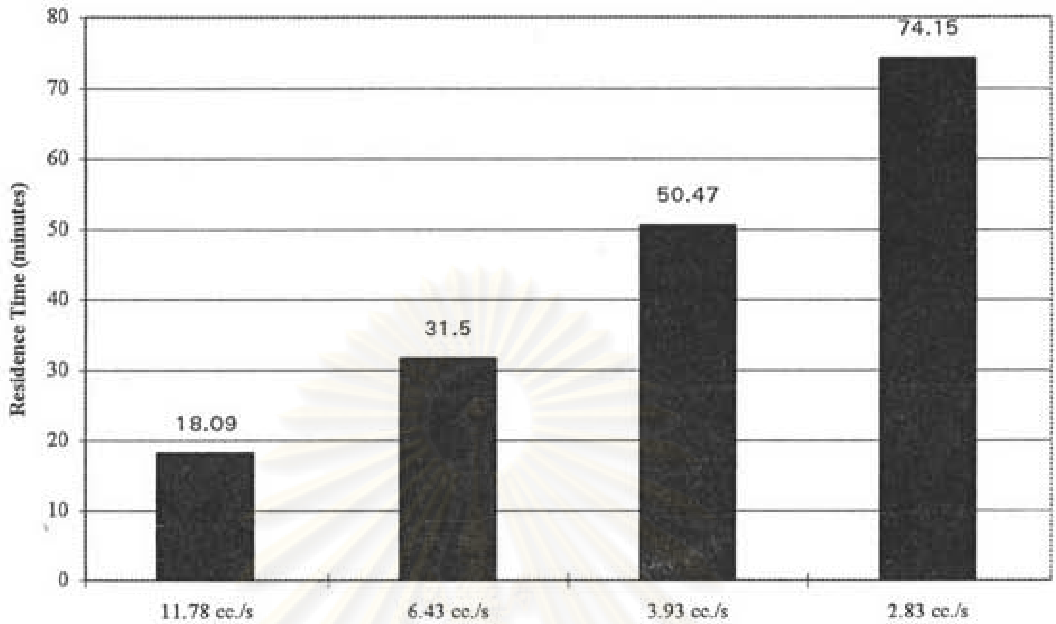


Figure 5.15 Comparison between the inlet flow rate of turbine at 1/3 of the tank diameter above the bottom with speed 412.18 rpm. in 30 cm tank diameter



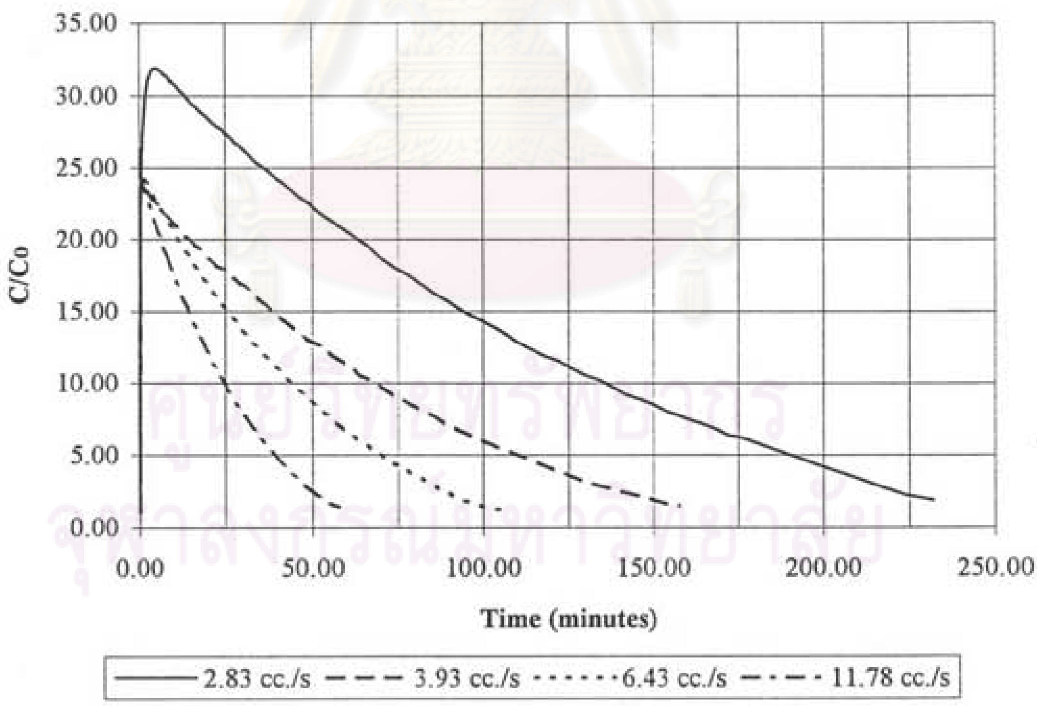
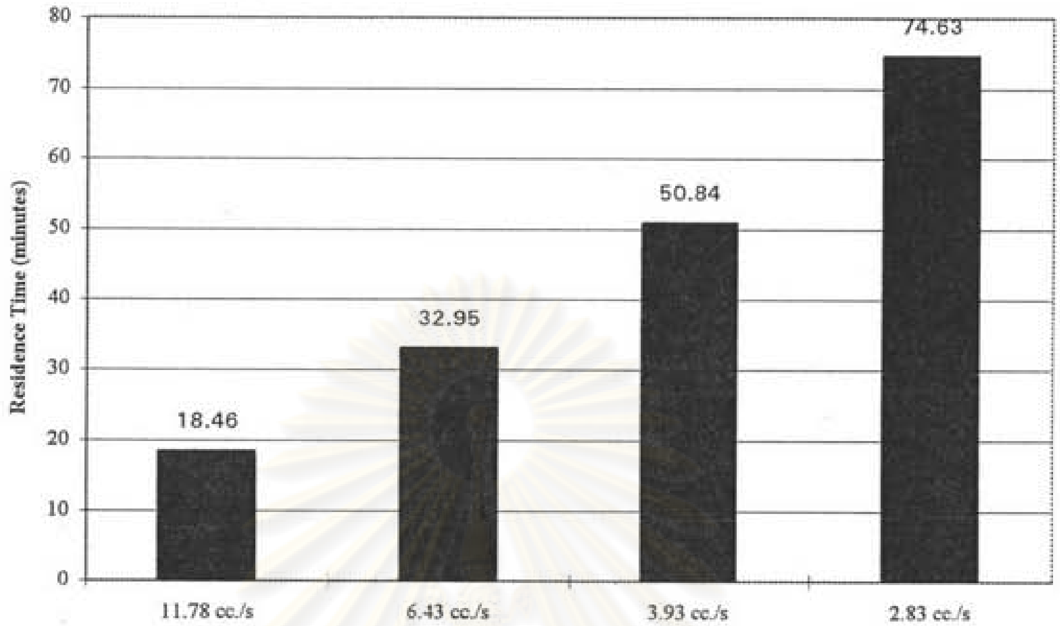


Figure 5.16 Comparison between the inlet flow rate of turbine at 1/2 of the tank diameter above the bottom with speed 176.58 rpm. in 30 cm tank diameter



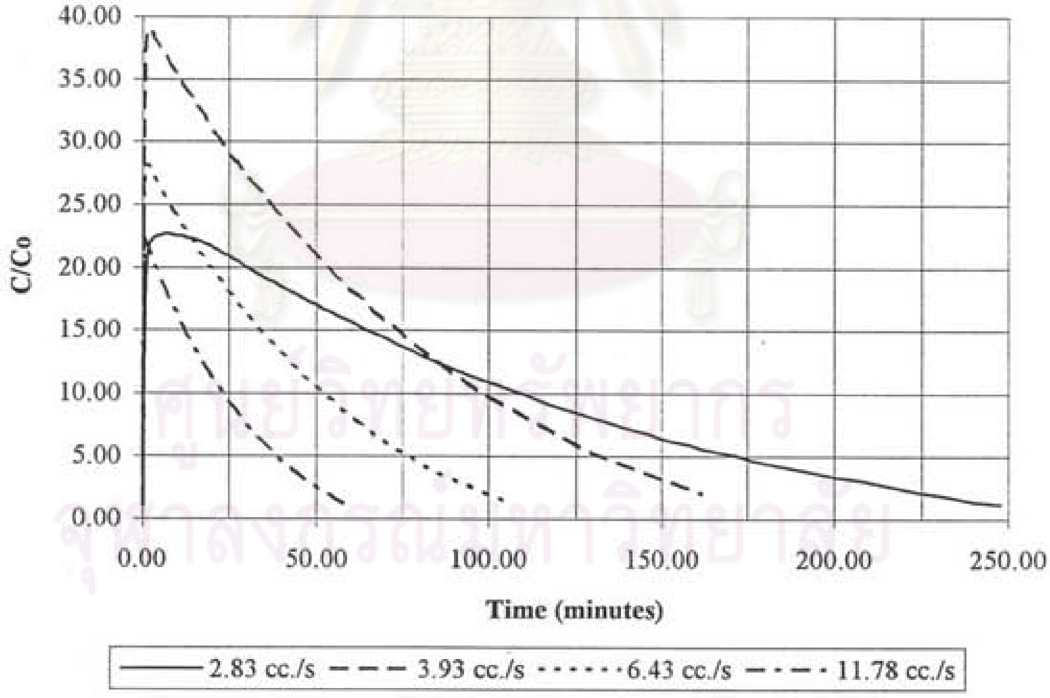


Figure 5.17 Comparison between the inlet flow rate of paddle at 1/3 of the tank diameter above the bottom with speed 176.58 rpm. in 30 cm tank diameter

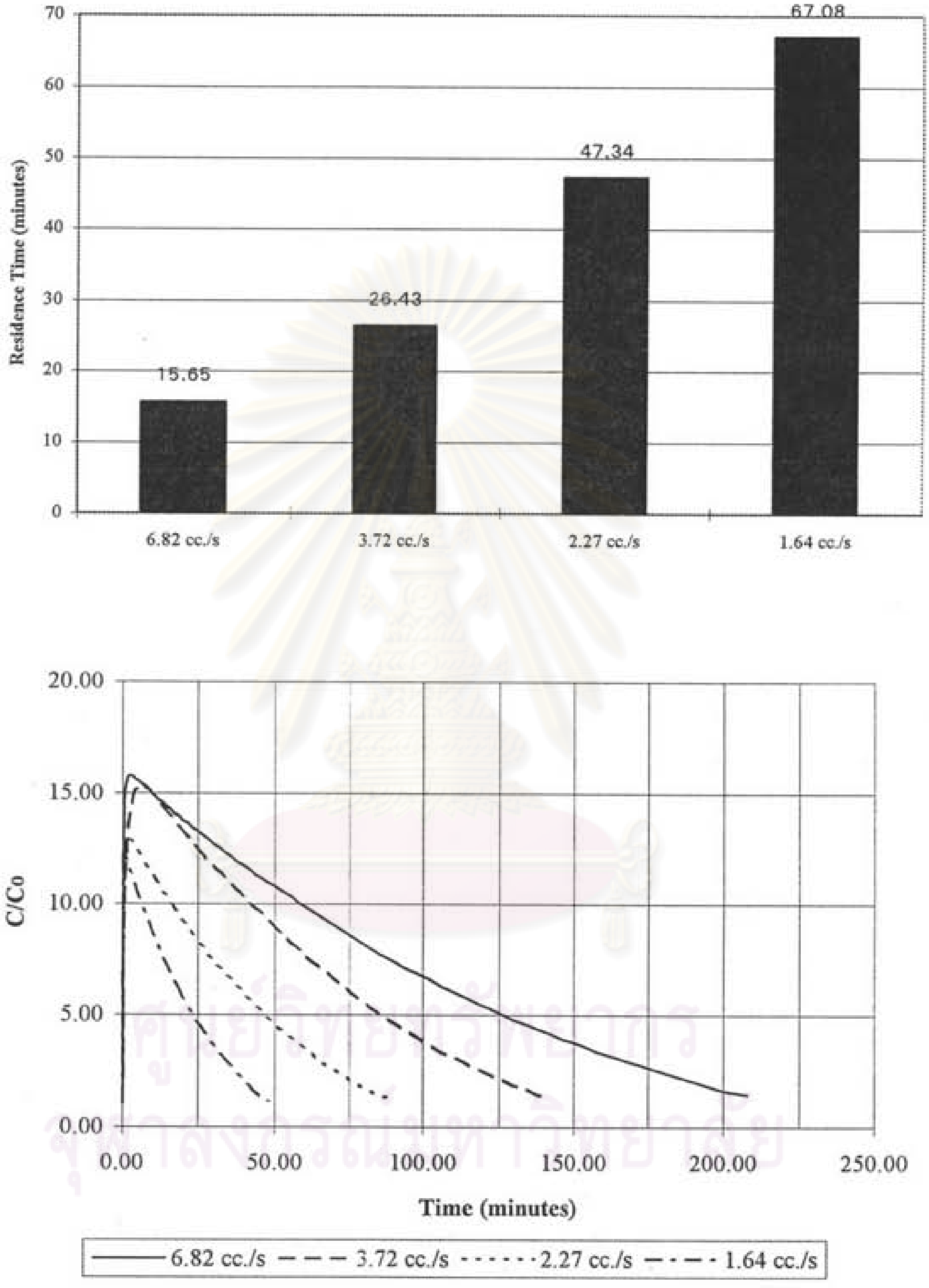


Figure 5.18 Comparison between the inlet flow rate of turbine at 1/3 of the tank diameter above the bottom with speed 353.256 rpm. in 25 cm tank diameter

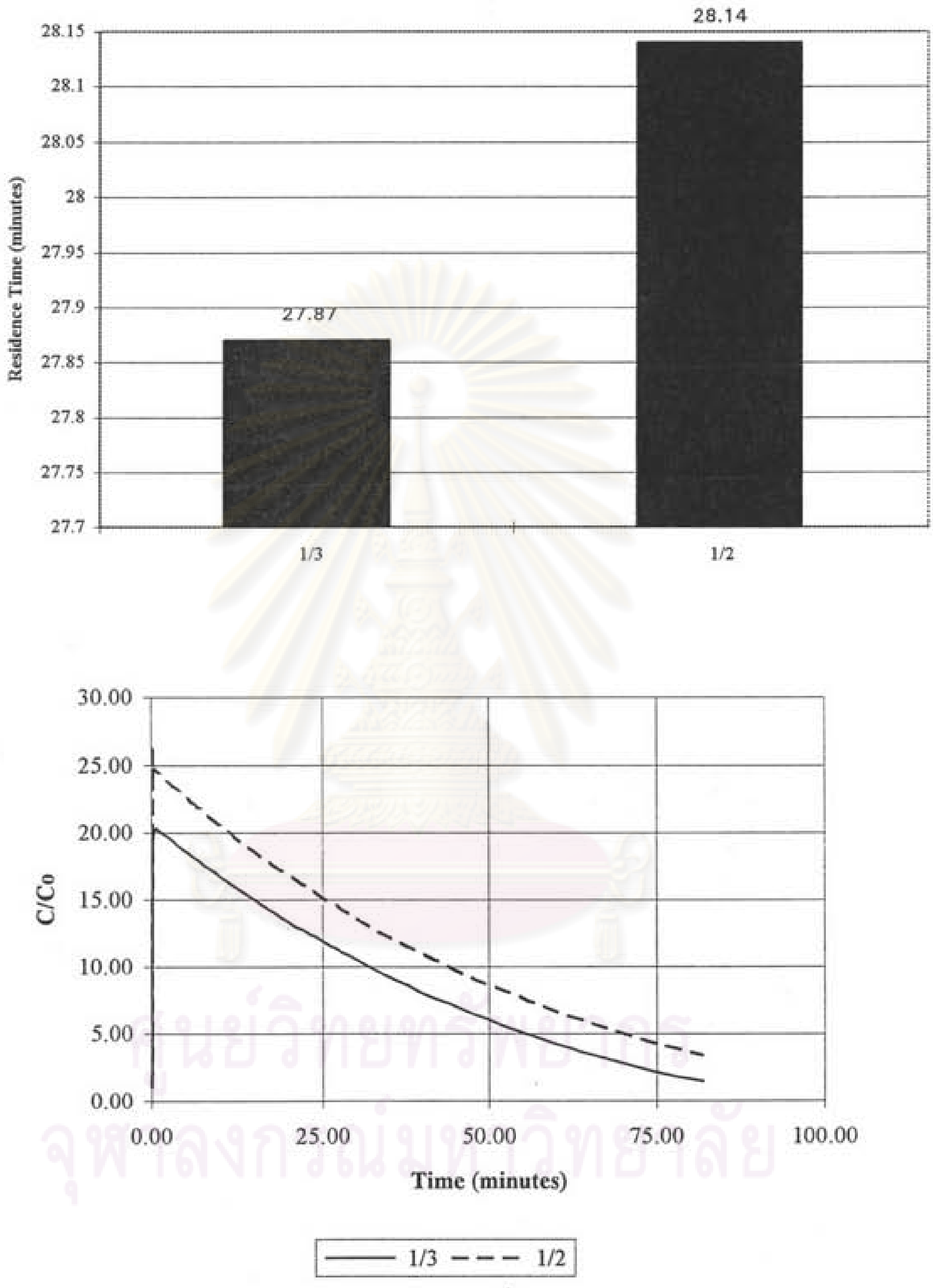
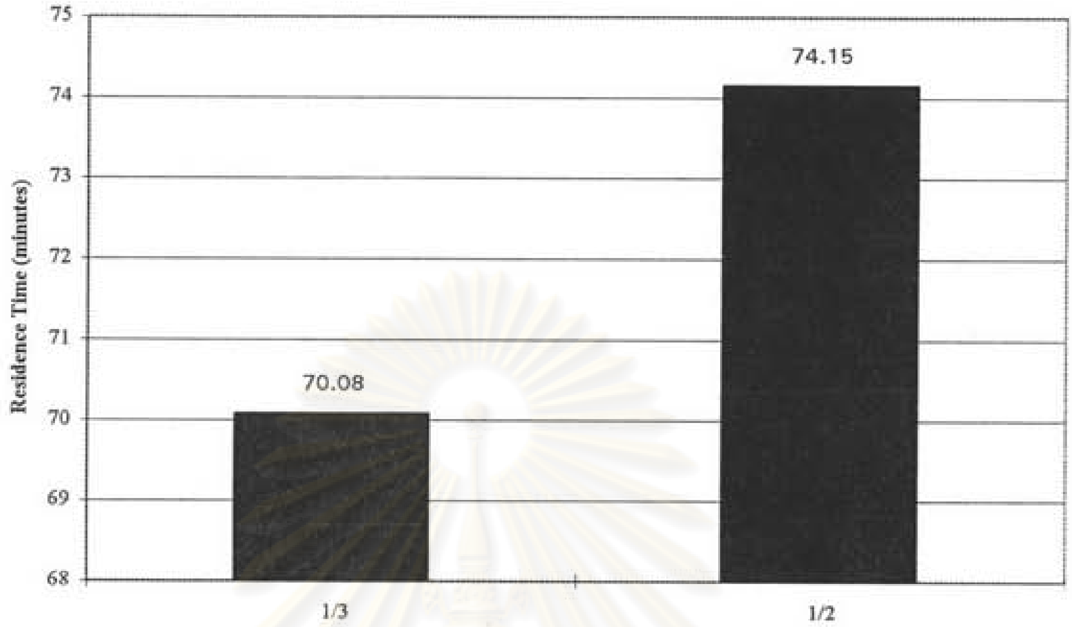


Figure 5.19 Comparison between the position of turbine above the bottom at 176.58 rpm. in 30 cm tank diameter (the mean residence time 55 minutes)



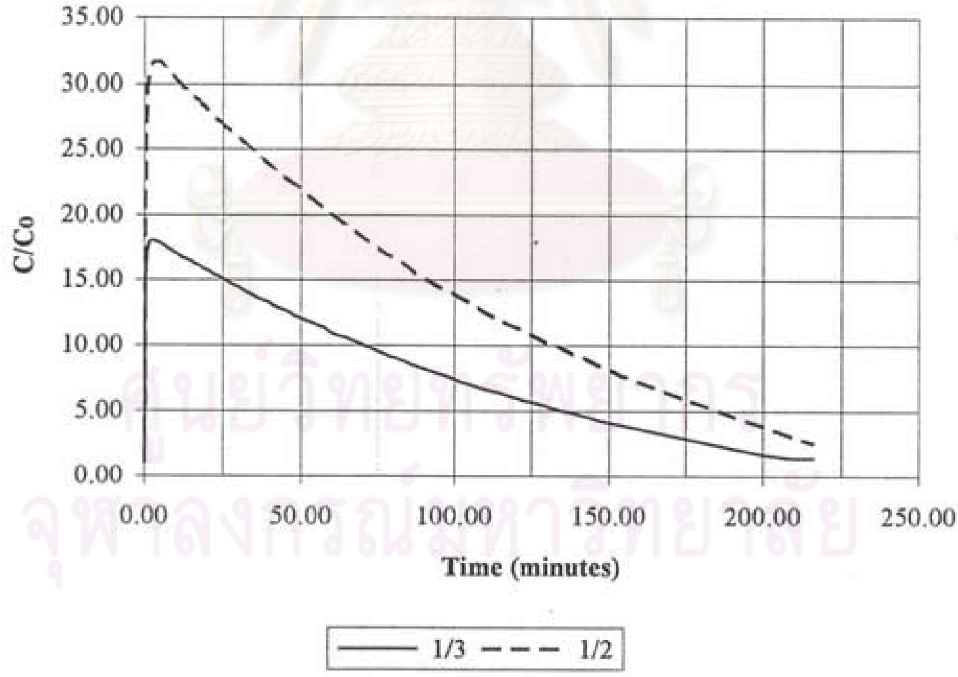
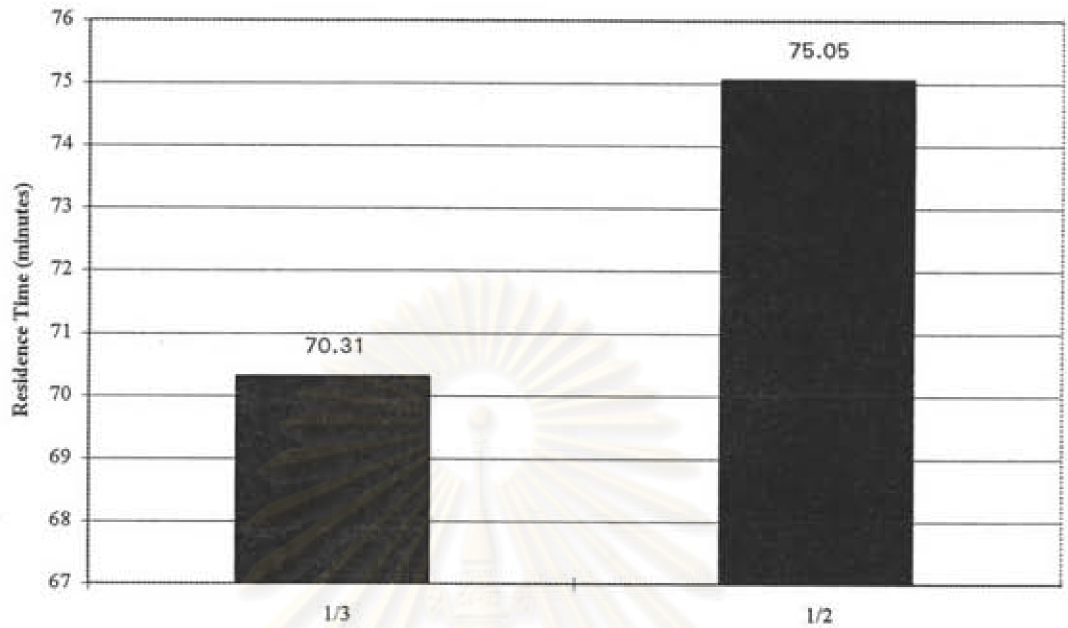


Figure 5.20 Comparison between the position of turbine above the bottom at 176.58 rpm. in 30 cm tank diameter (the mean residence time 125 minutes)



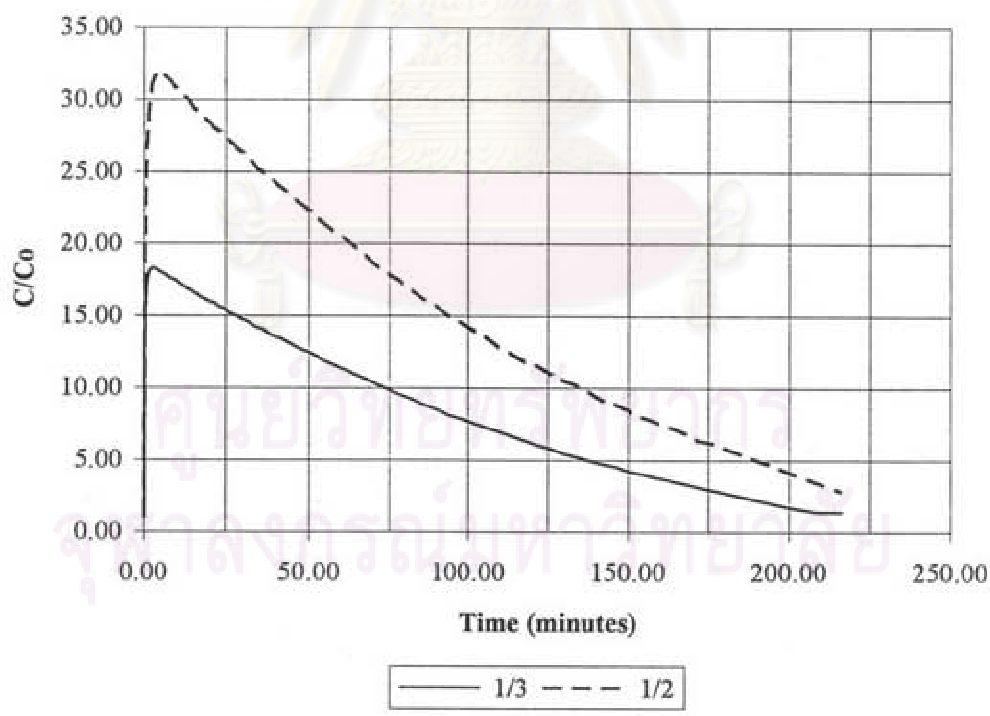
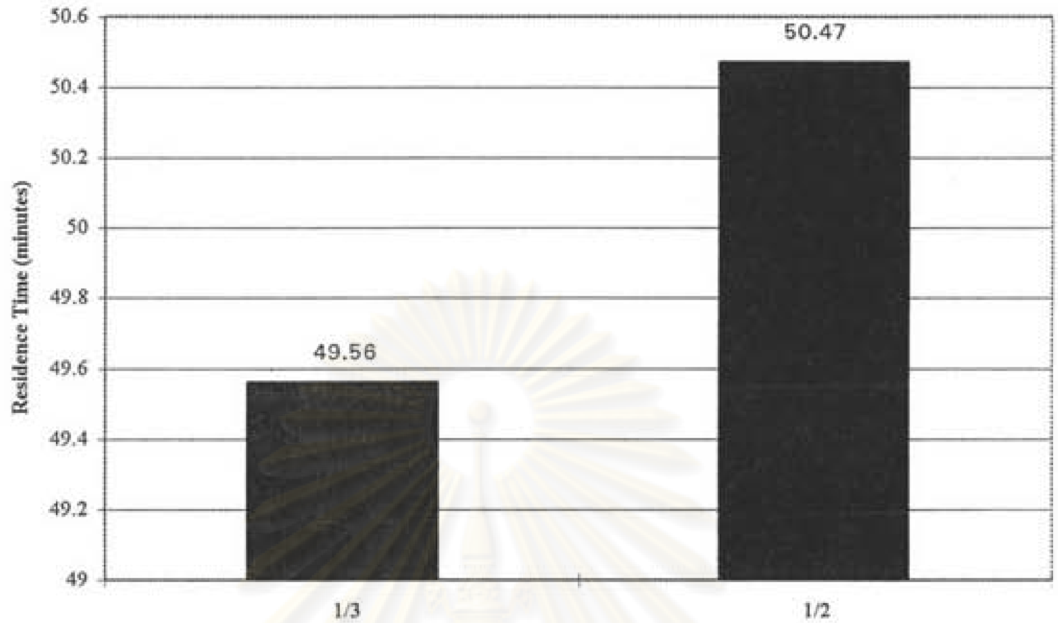


Figure 5.21 Comparison between the position of turbine above the bottom at 294.38 rpm. in 30 cm tank diameter (the mean residence time 125 minutes)



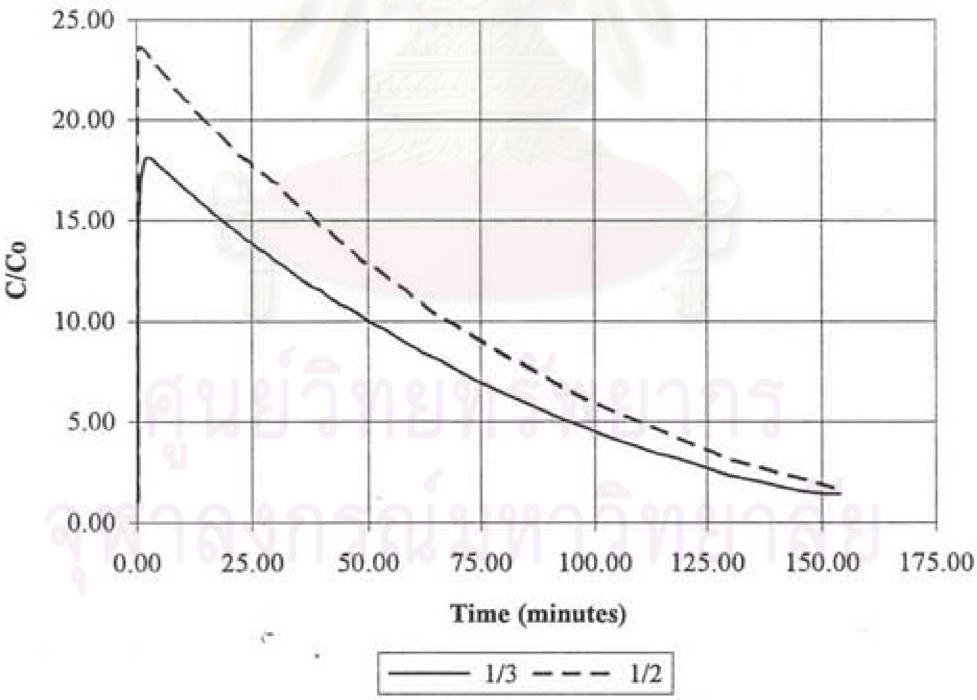
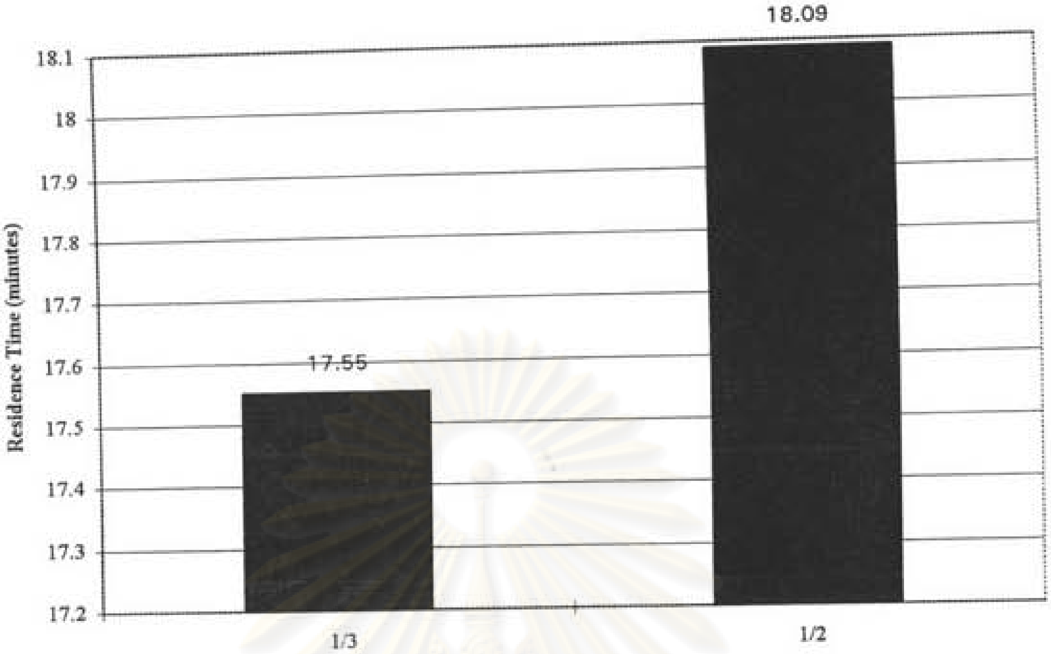


Figure 5.22 Comparison between the position of turbine above the bottom at 176.58 rpm. in 30 cm tank diameter (the mean residence time 90 minutes)



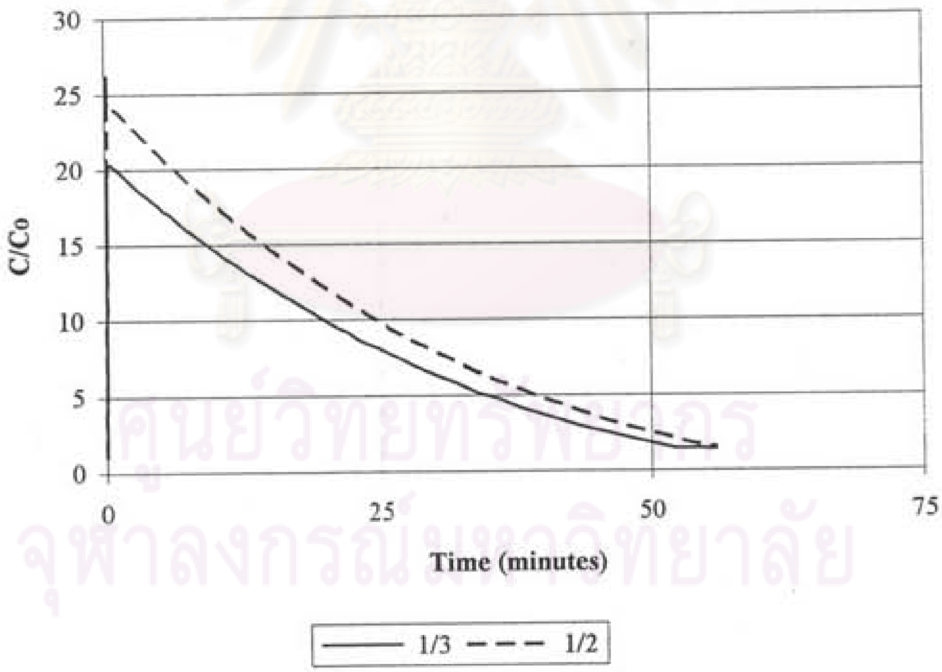
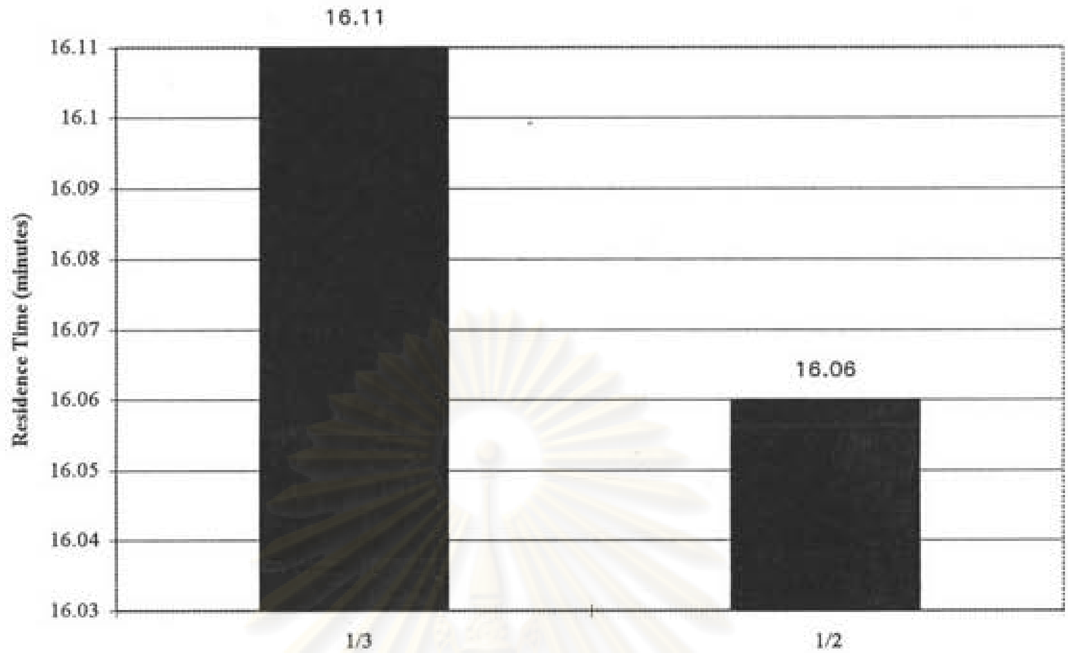


Figure 5.23 Comparison between the position of turbine above the bottom at 176.58 rpm. in 30 cm tank diameter (the mean residence time 30 minutes)



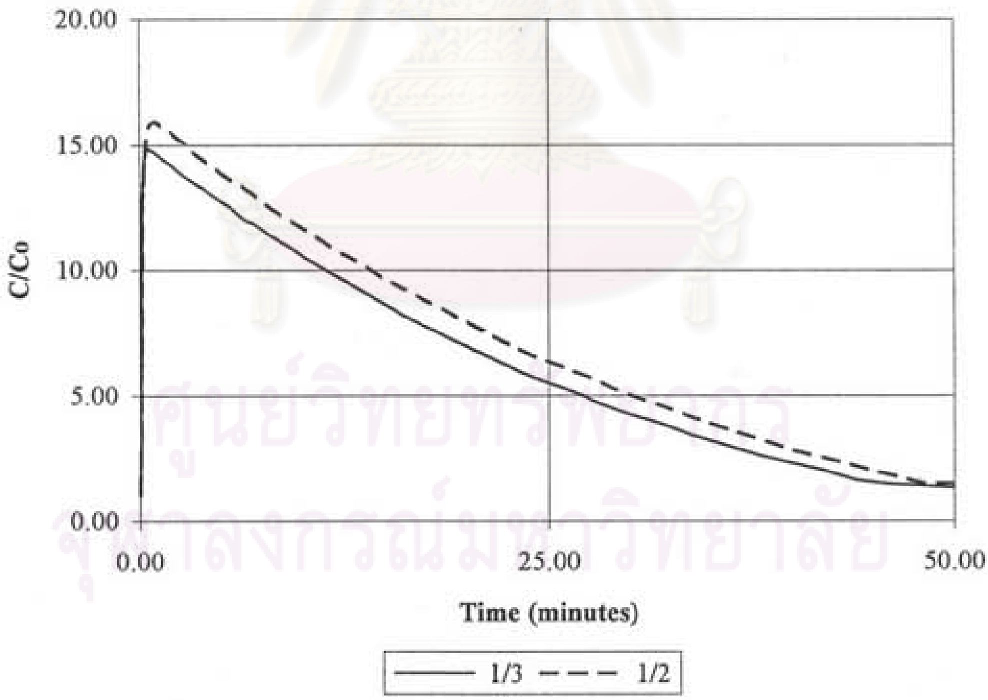
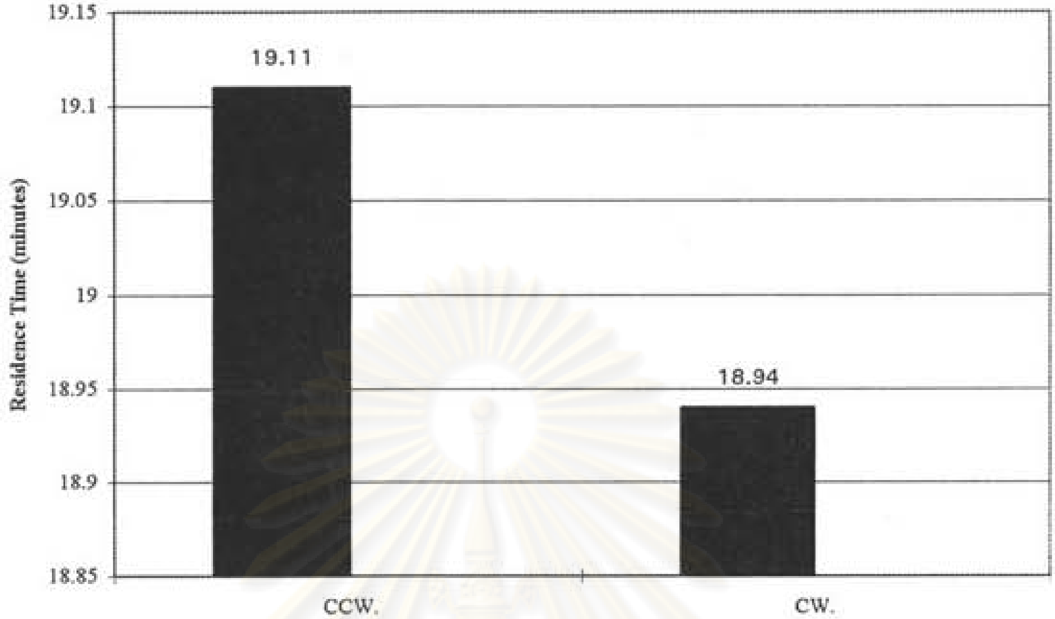


Figure 5.24 Comparison between the position of paddle above the bottom at 211.90 rpm. in 25 cm tank diameter (the mean residence time 30 minutes)



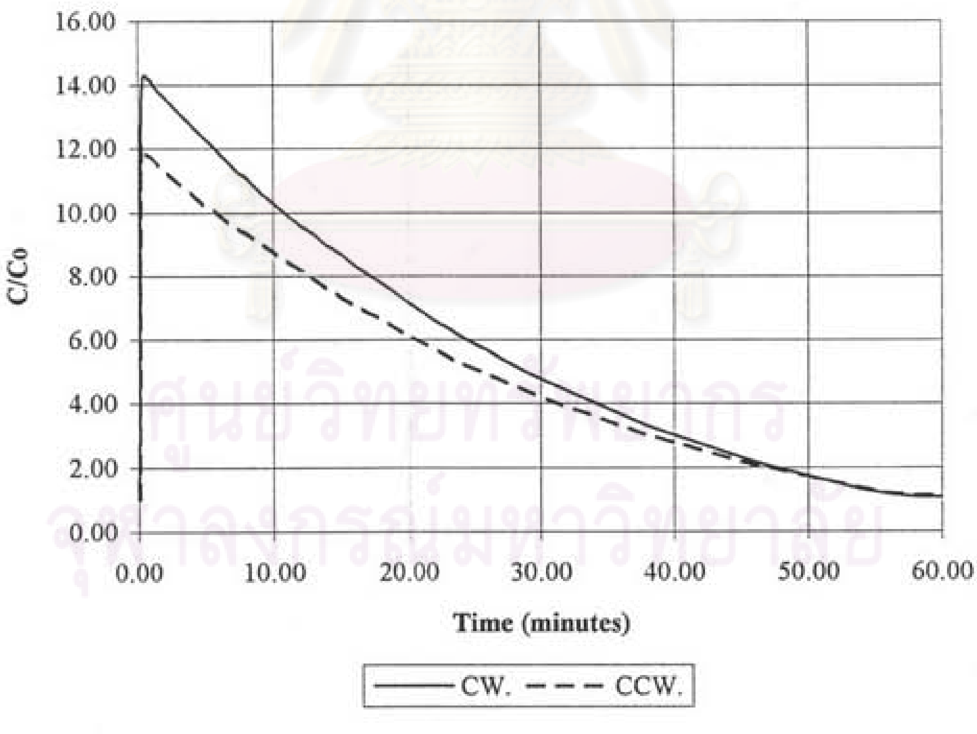


Figure 5.25 Comparison between the direction of 45 degree Pitch Impeller at 1/3 of the tank diameter above the bottom with speed 176.58 rpm. in 30 cm tank diameter (the mean residence time 30 minutes)

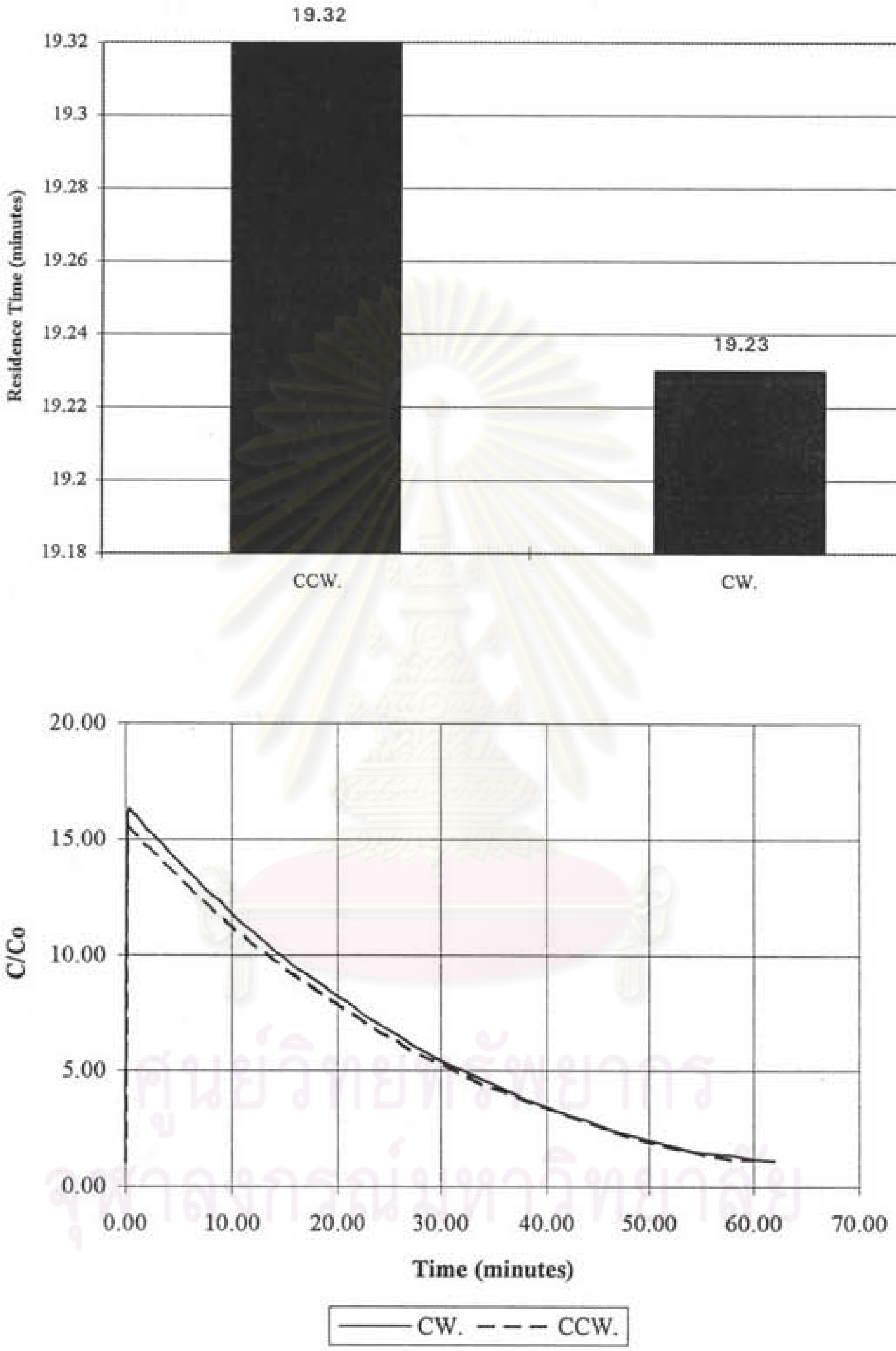
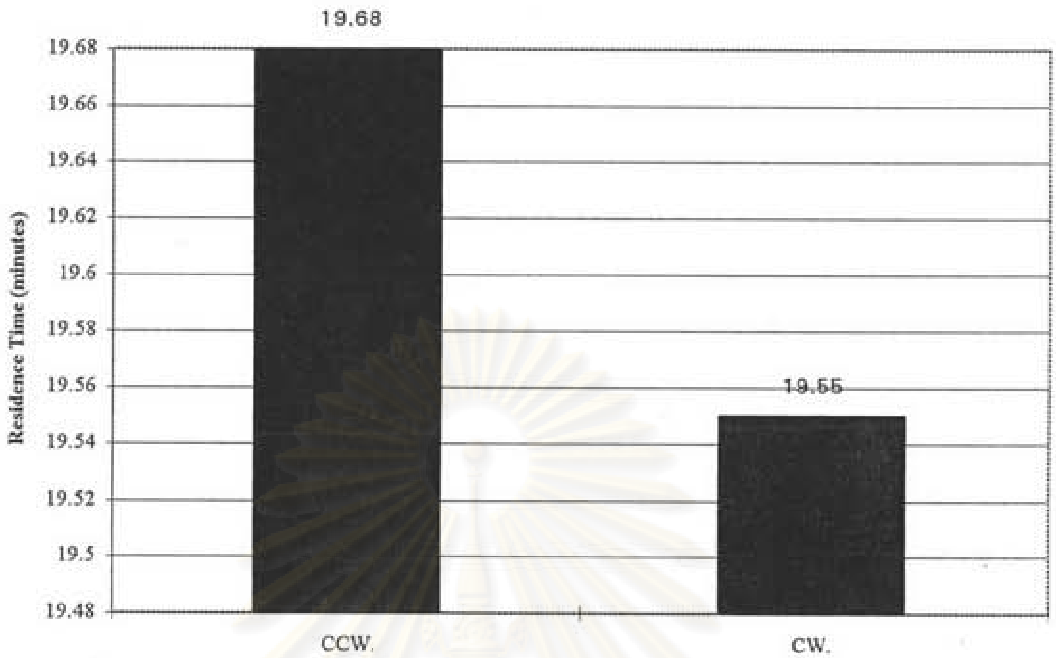


Figure 5.26 Comparison between the direction of 45 degree Pitch Impeller at 1/3 of the tank diameter above the bottom with speed 294.38 rpm. in 30 cm tank diameter (the mean residence time 30 minutes)



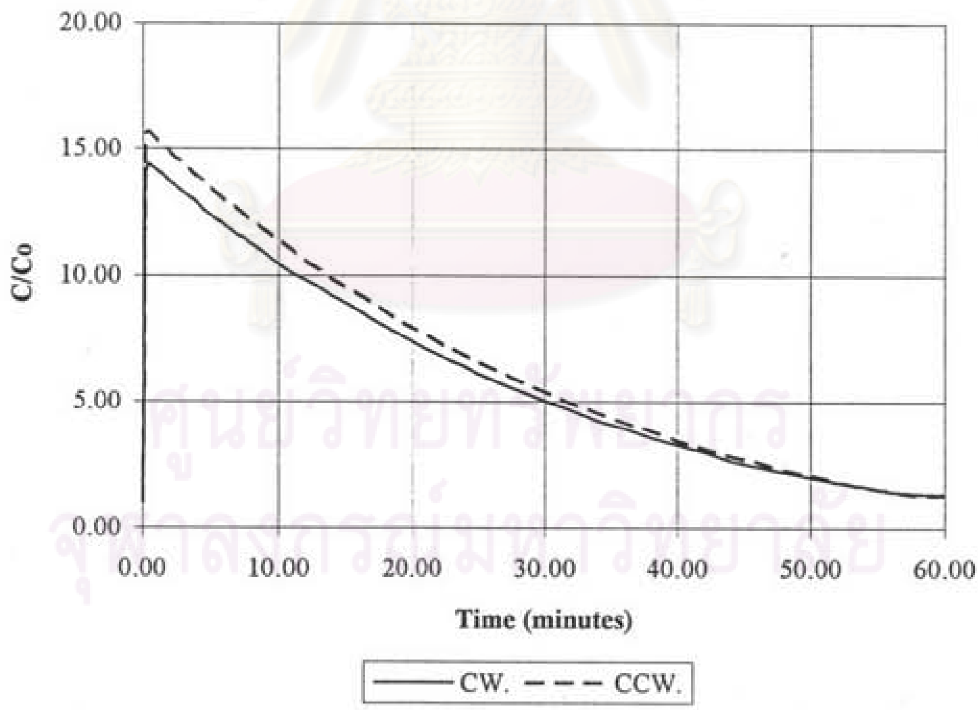
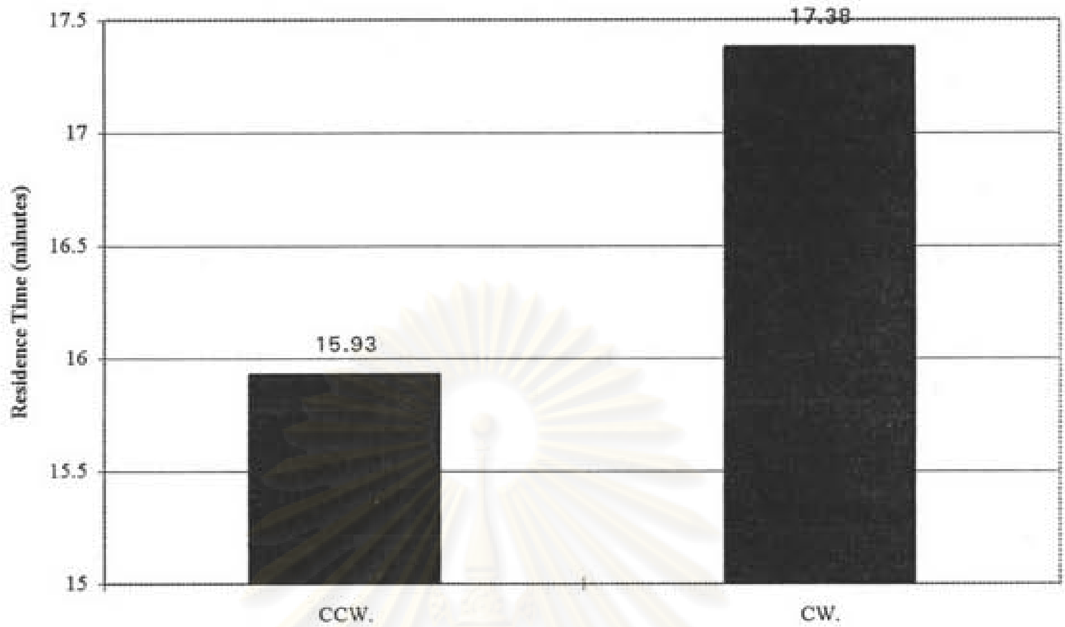


Figure 5.27 Comparison between the direction of 45 degree Pitch Impeller at 1/3 of the tank diameter above the bottom with speed 412.18 rpm. in 30 cm tank diameter (the mean residence time 30 minutes)



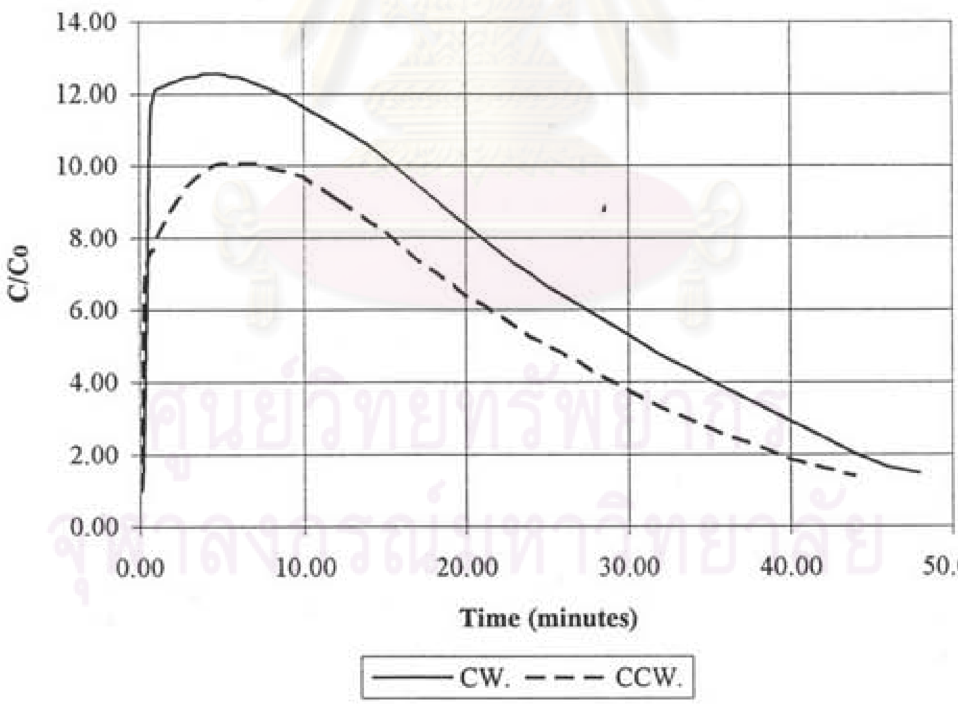


Figure 5.28 Comparison between the direction of 45 degree Pitch Impeller at 1/3 of the tank diameter above the bottom with speed 264.87 rpm. in 20 cm tank diameter (the mean residence time 30 minutes)

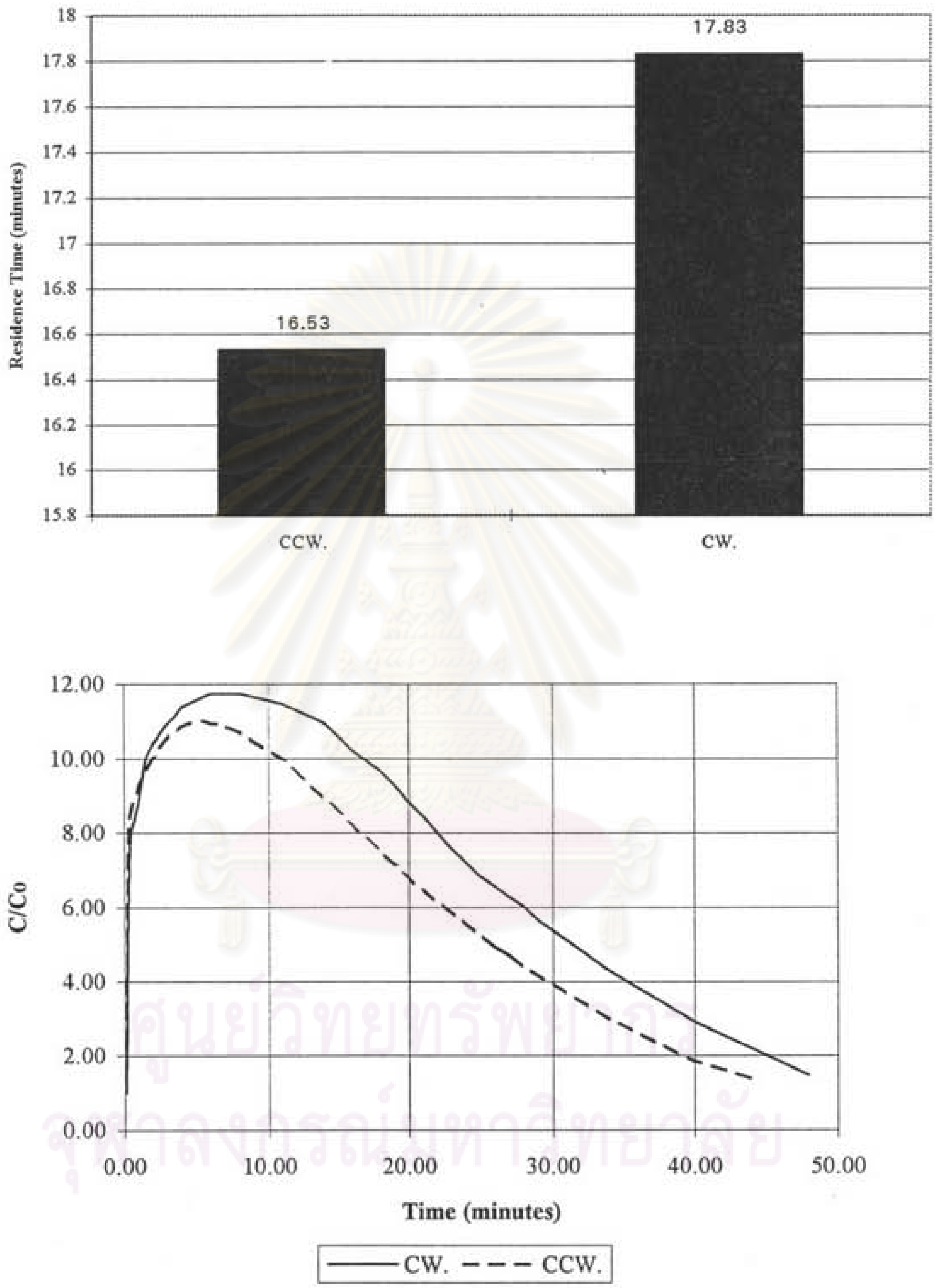
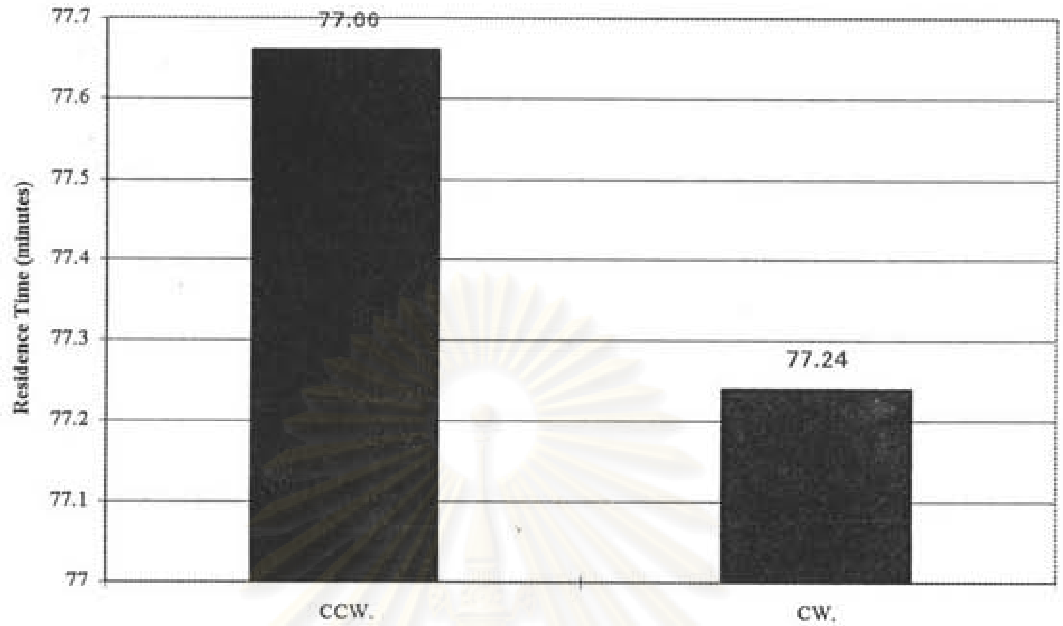


Figure 5.29 Comparison between the direction of 45 degree Pitch Impeller at 1/3 of the tank diameter above the bottom with speed 441.57 rpm. in 20 cm tank diameter (the mean residence time 30 minutes)



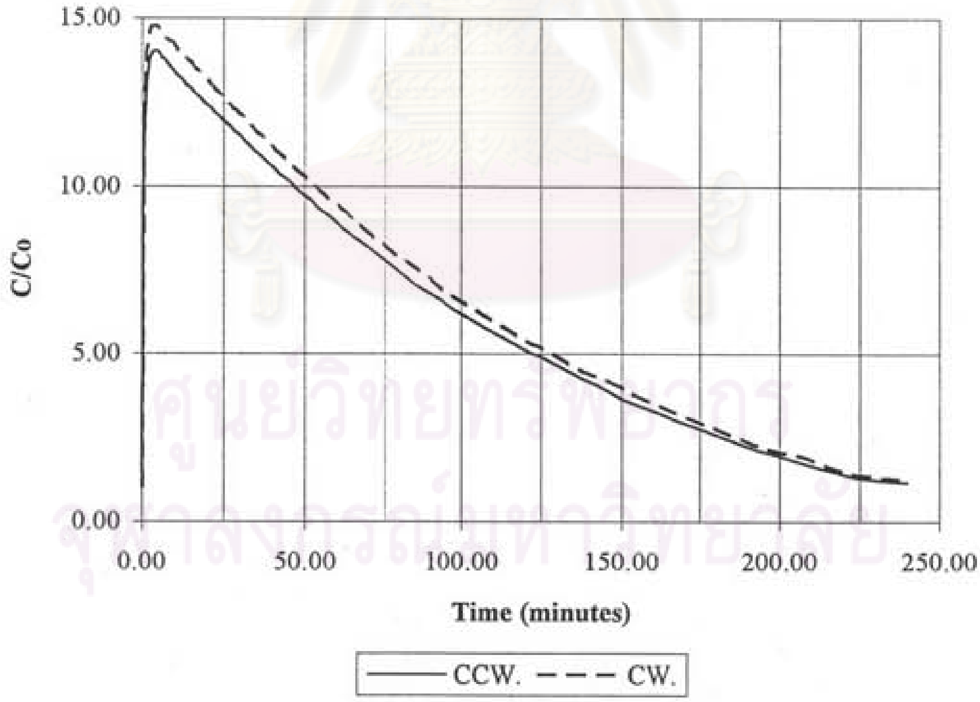
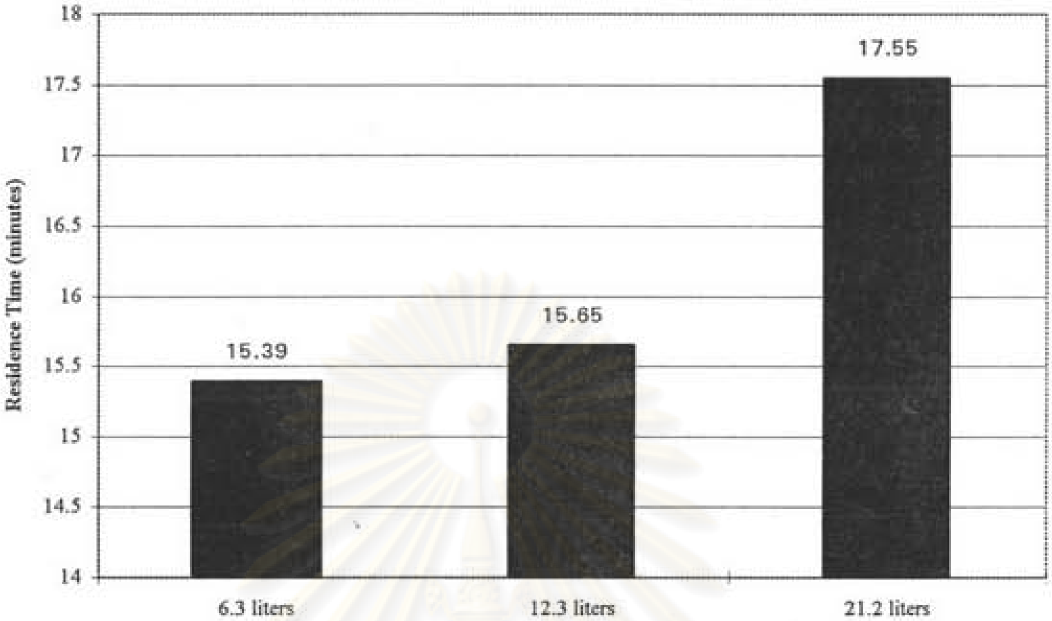


Figure 5.30 Comparison between the direction of 45 degree Pitch Impeller at 1/3 of the tank diameter above the bottom with speed 176.58 rpm. in 30 cm tank diameter (the mean residence time 125 minutes)



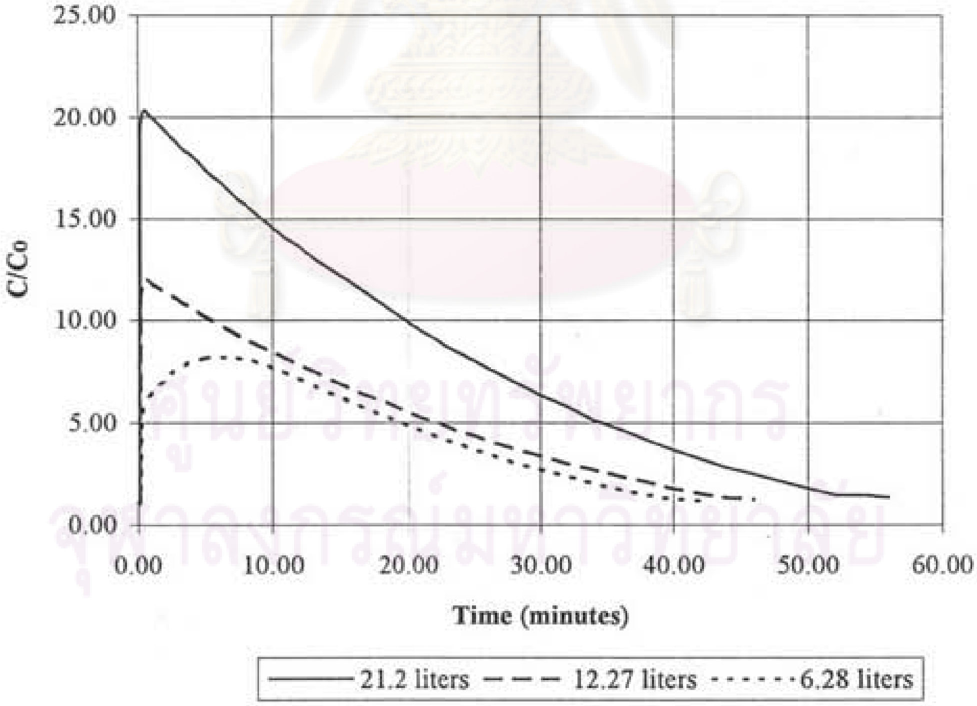
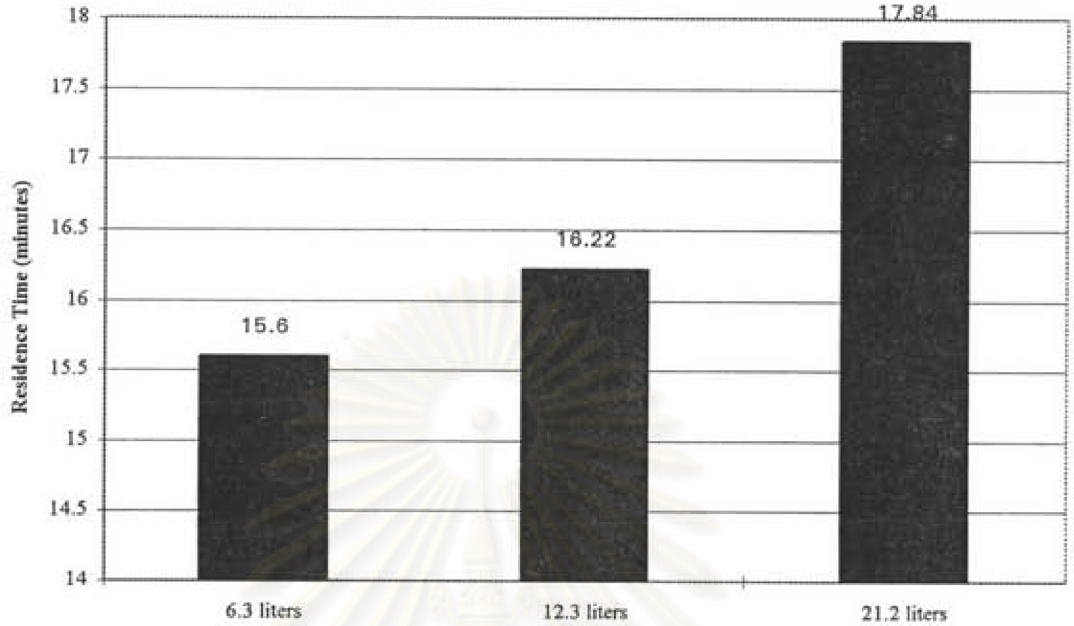


Figure 5.31 Comparison between the size of the tank using turbine at 1/3 above the bottom at 176.58 rpm. (mean residence time 30 minutes)



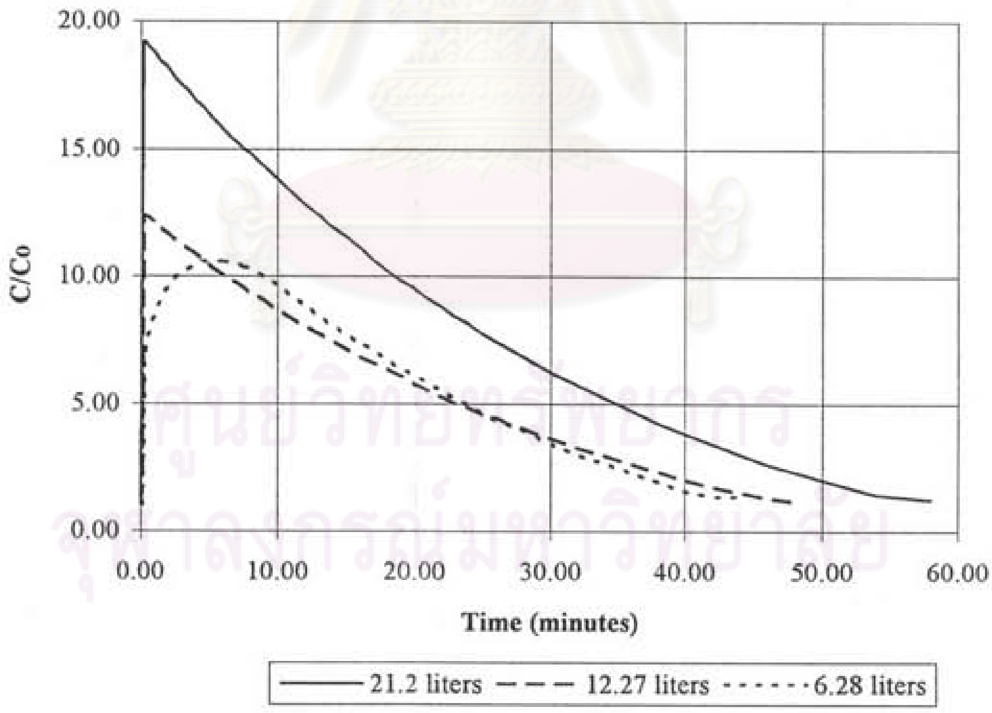
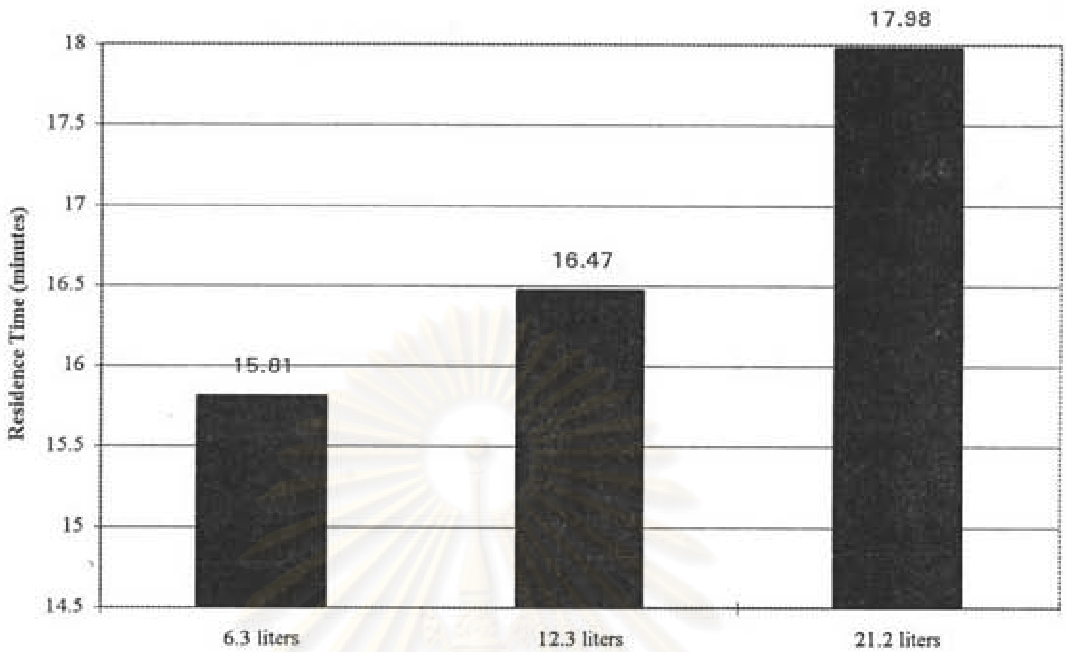


Figure 5.32 Comparison between the size of the tank using turbine at 1/3 above the bottom at 294.38 rpm. (mean residence time 30 minutes)



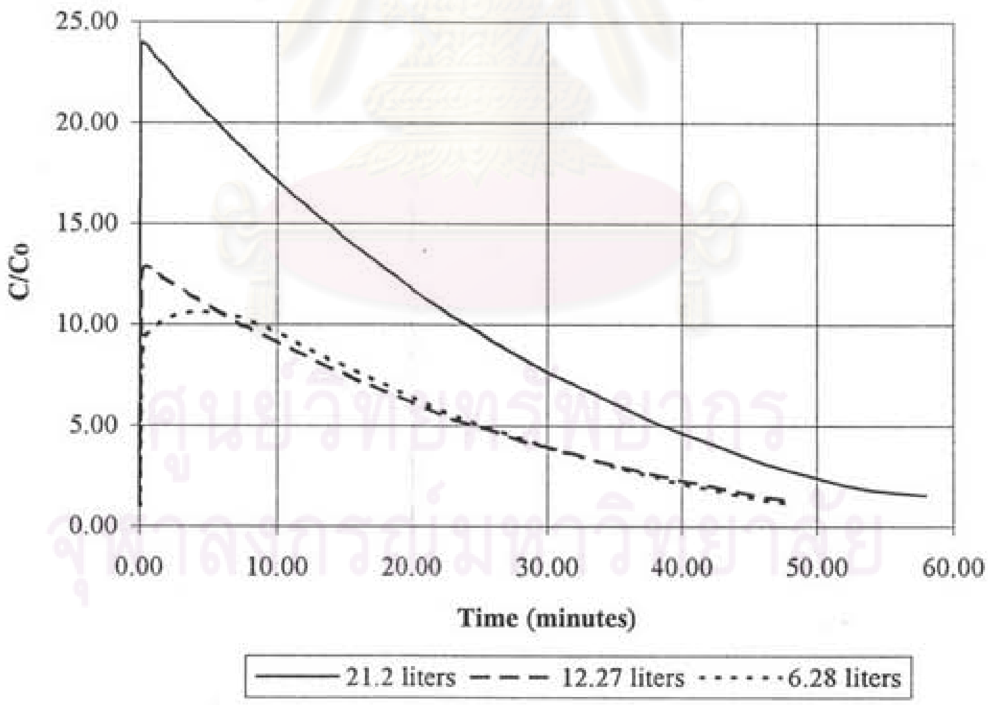
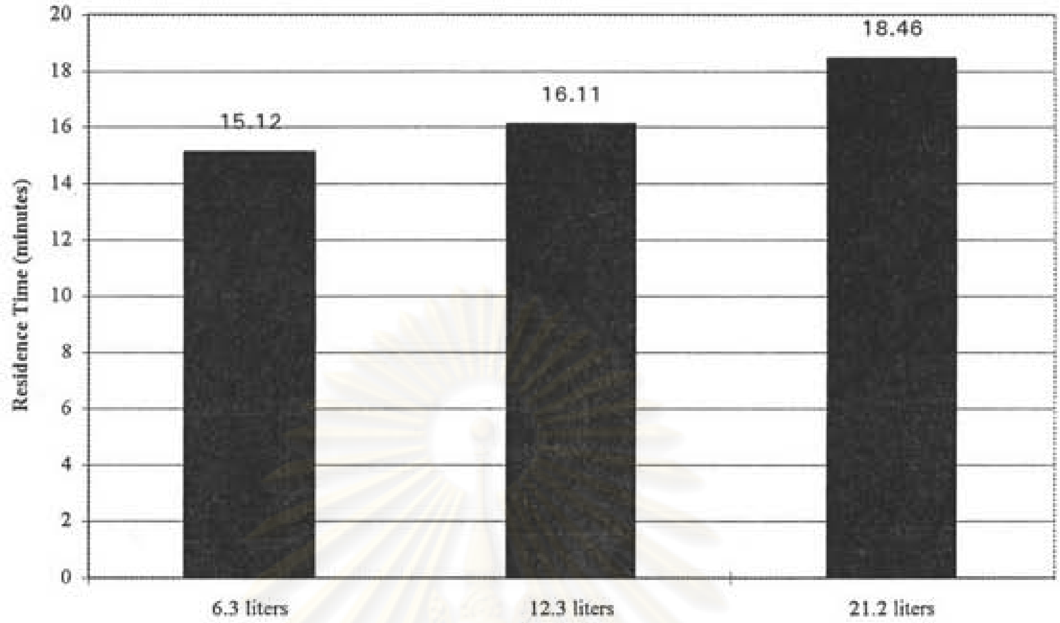


Figure 5.33 Comparison between the size of the tank using turbine at 1/3 above the bottom at 412.18 rpm. (mean residence time 30 minutes)



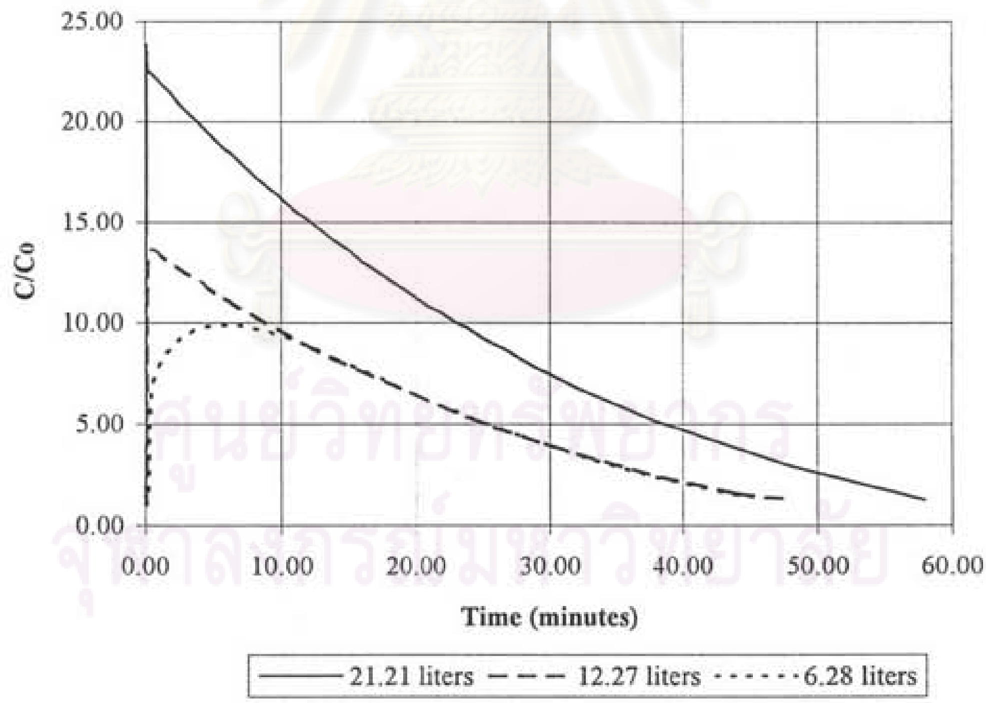


Figure 5.34 Comparison between the size of the tank using paddle at 1/3 above the bottom at 264.87 rpm. (mean residence time 30 minutes)

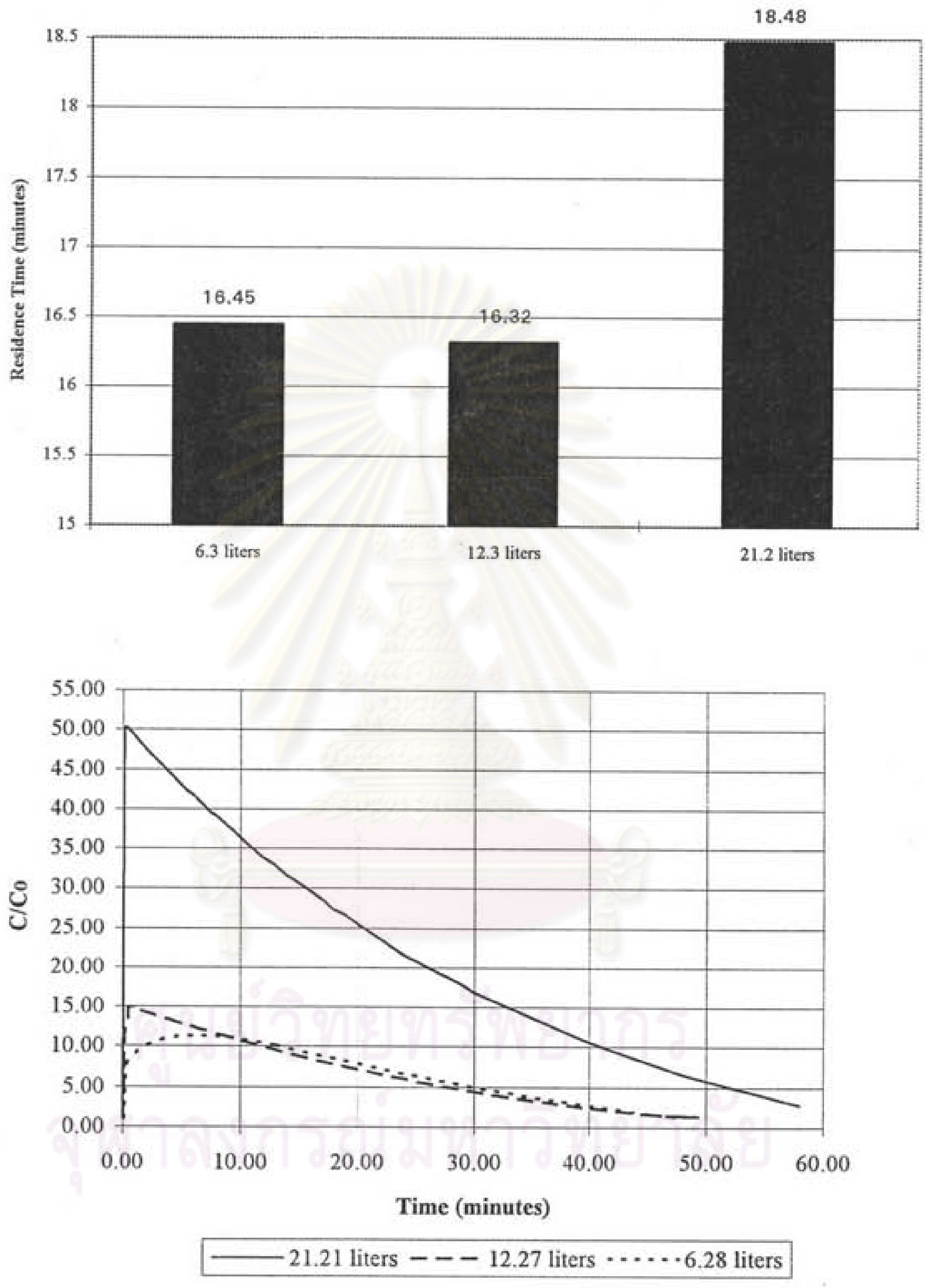
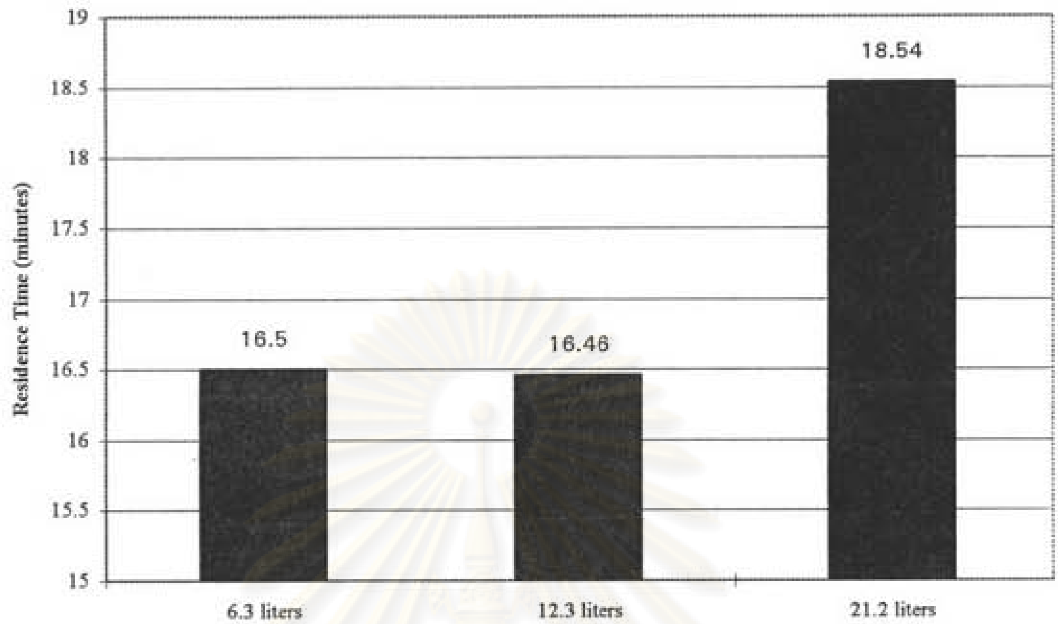


Figure 5.35 Comparison between the size of the tank using paddle at 1/3 above the bottom at 441.57 rpm. (mean residence time 30 minutes)



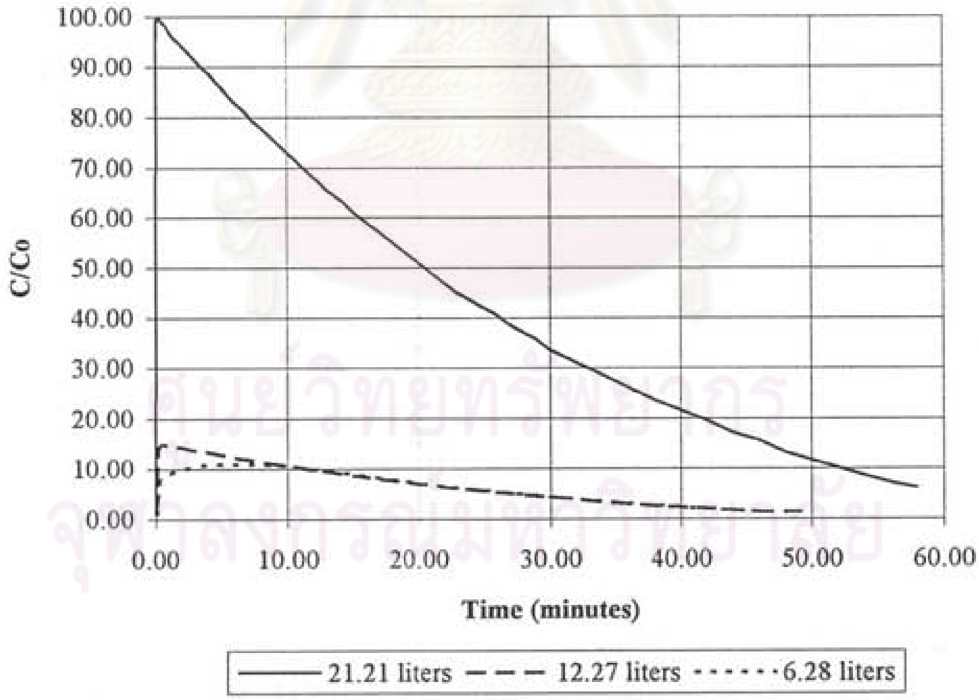
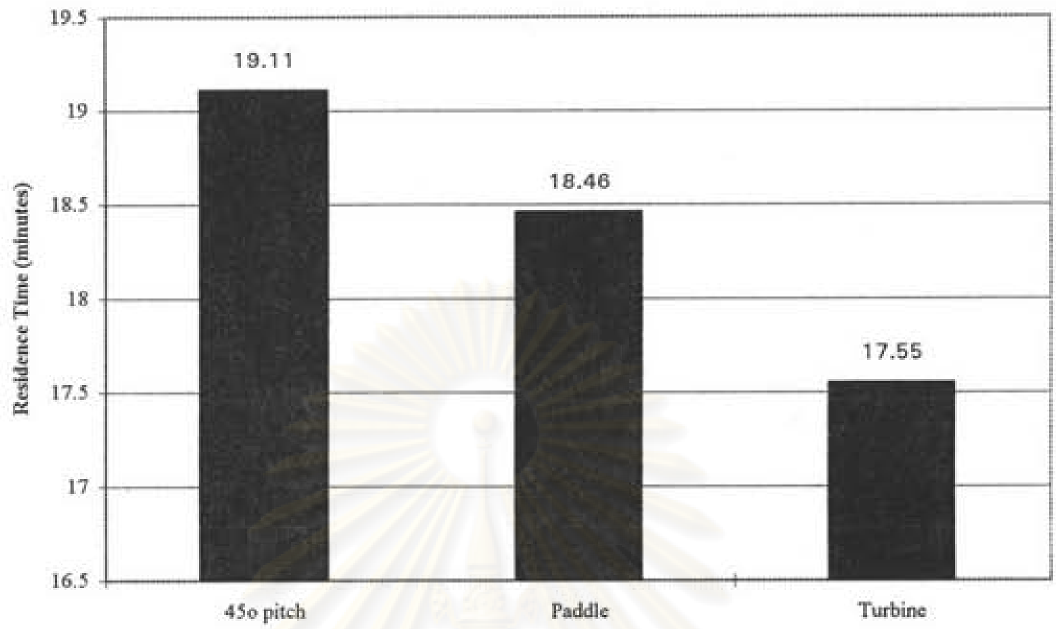


Figure 5.36 Comparison between the size of the tank using paddle at 1/3 above the bottom at 618.27 rpm. (mean residence time 30 minutes)



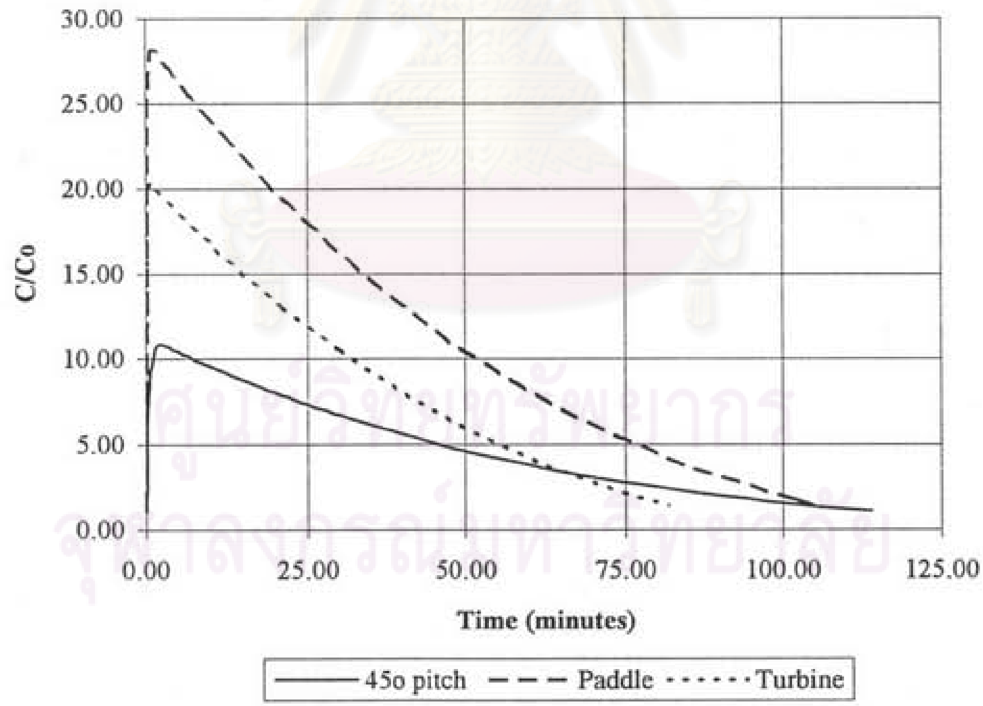
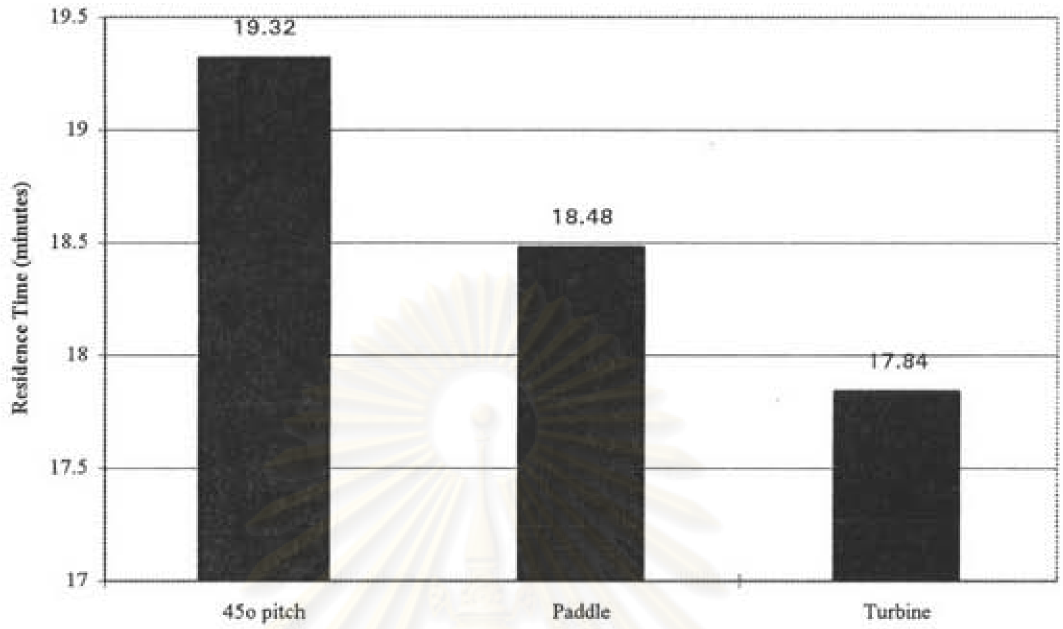


Figure 5.37 Comparison between the types of impeller at 1/3 of the tank diameter above the bottom (176.58 rpm.) in 30 cm tank diameter (the mean residence time 30 minutes)



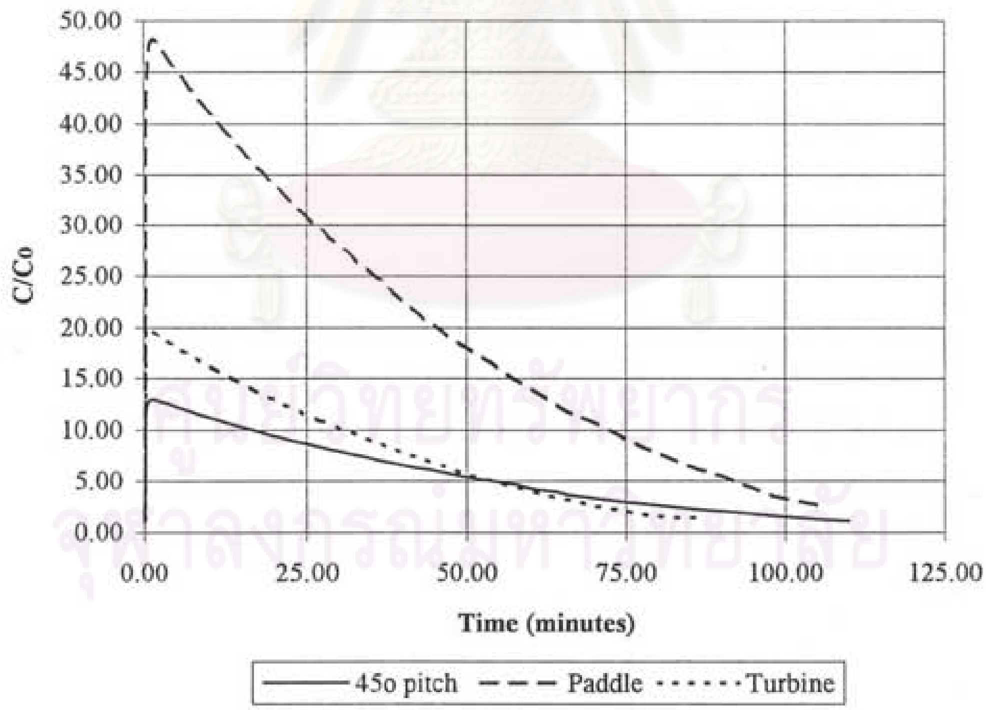


Figure 5.38 Comparison between the types of impeller at 1/3 of the tank diameter above the bottom (294.38 rpm.) in 30 cm tank diameter (the mean residence time 30 minutes)

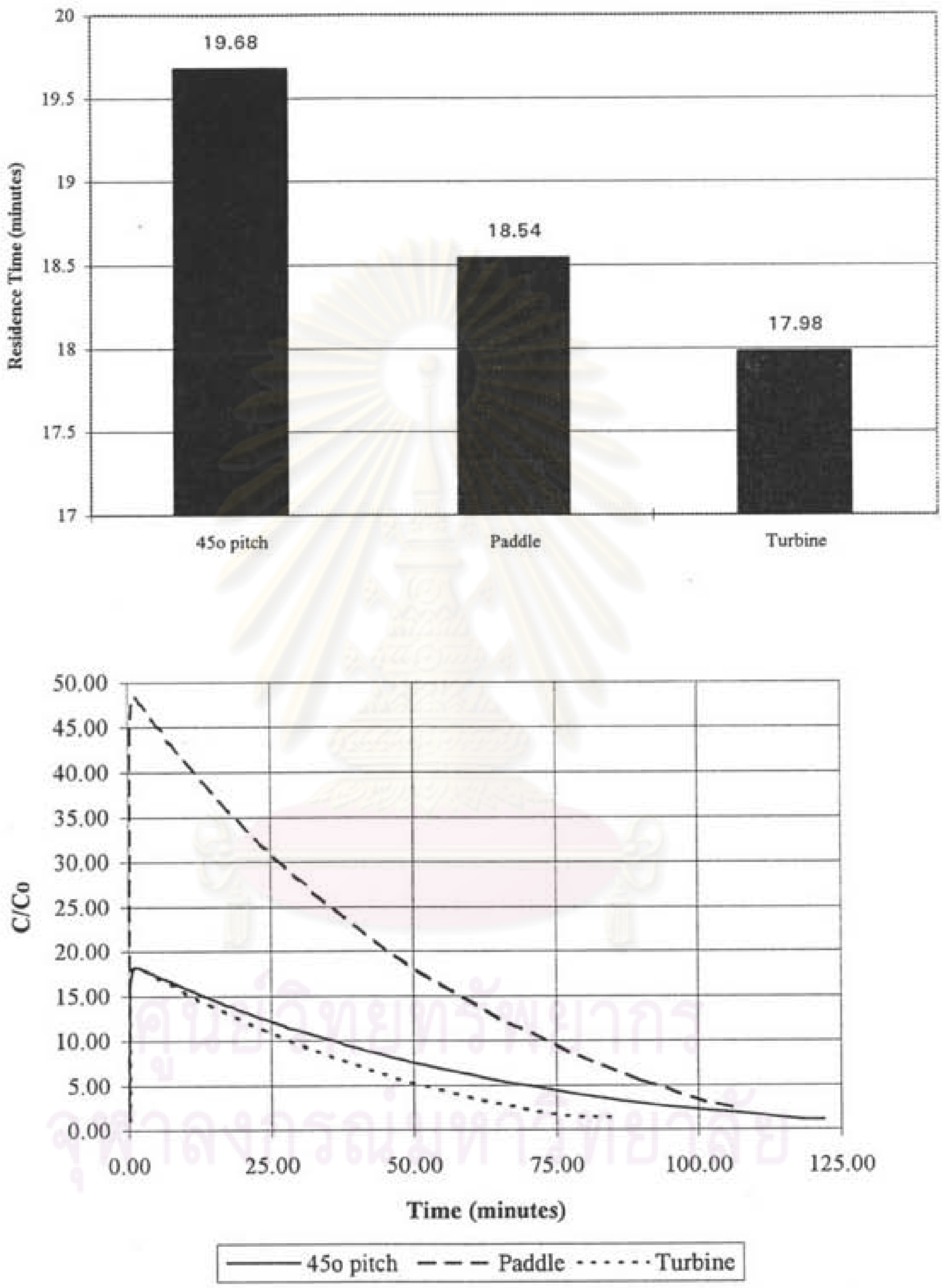
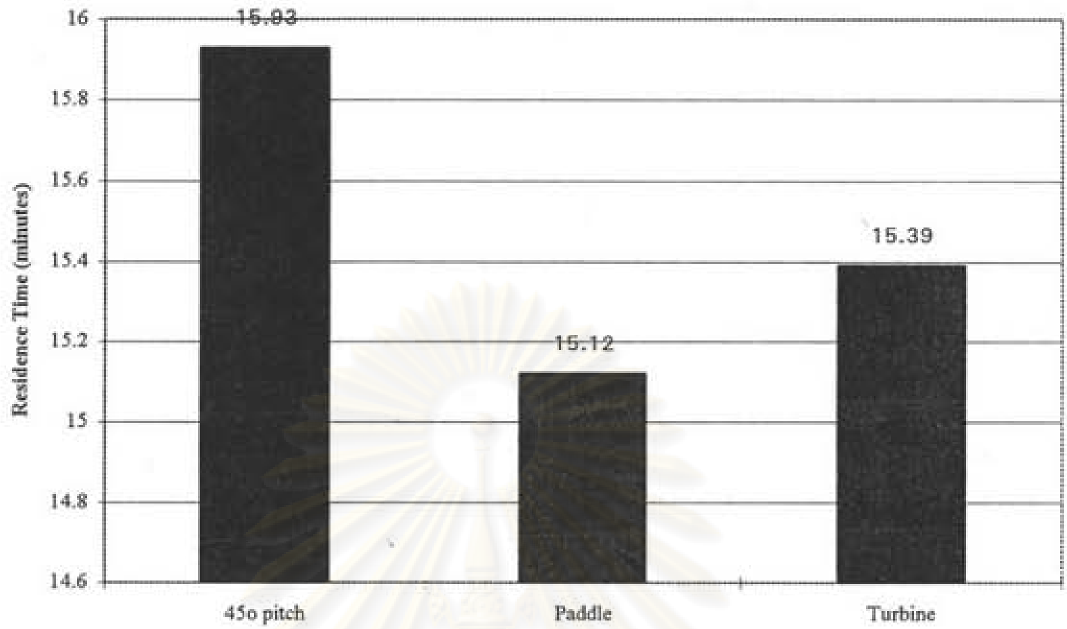


Figure 5.39 Comparison between the types of impeller at 1/3 of the tank diameter above the bottom (412.18 rpm.) in 30 cm tank diameter (the mean residence time 30 minutes)



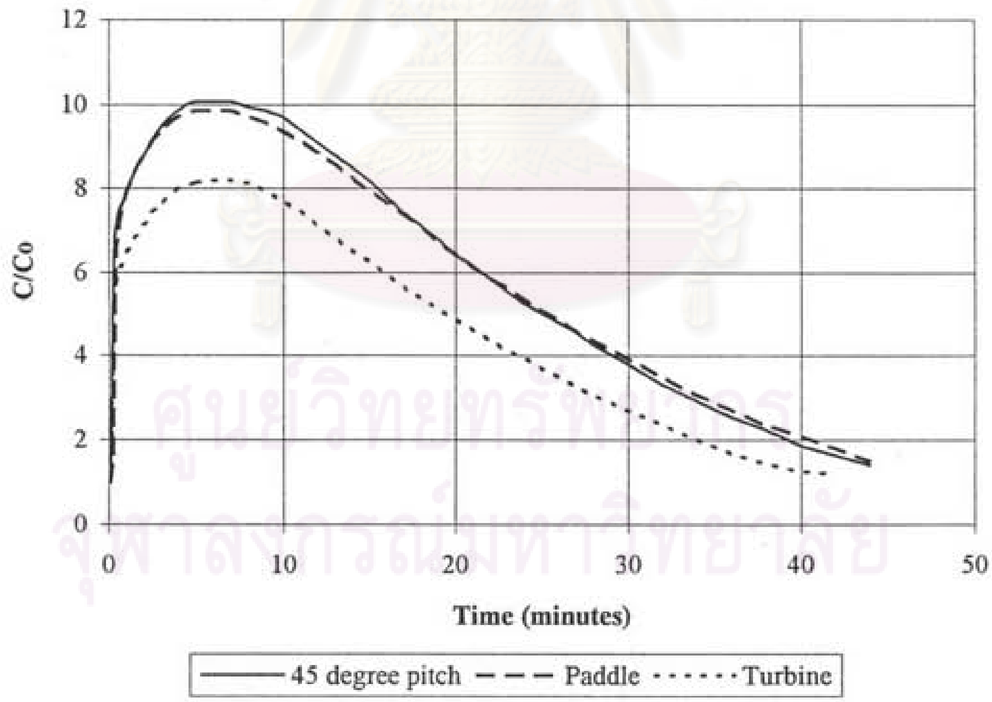
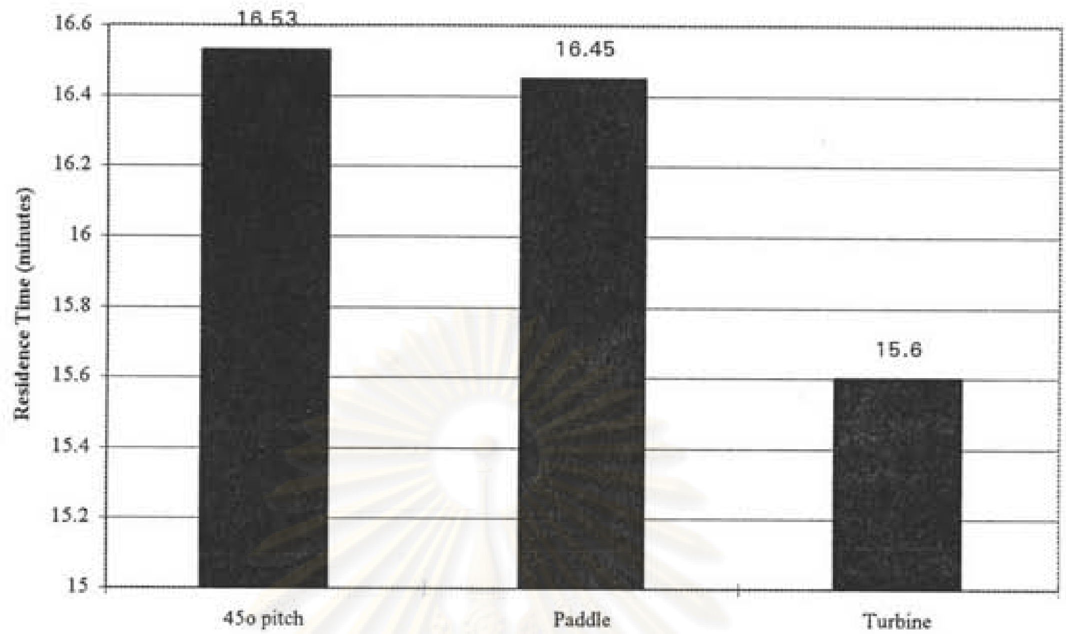


Figure 5.40 Comparison between the types of impeller at 1/3 of the tank diameter above the bottom (264.87 rpm.) in 20 cm. tank diameter (the mean residence time 30 minutes)



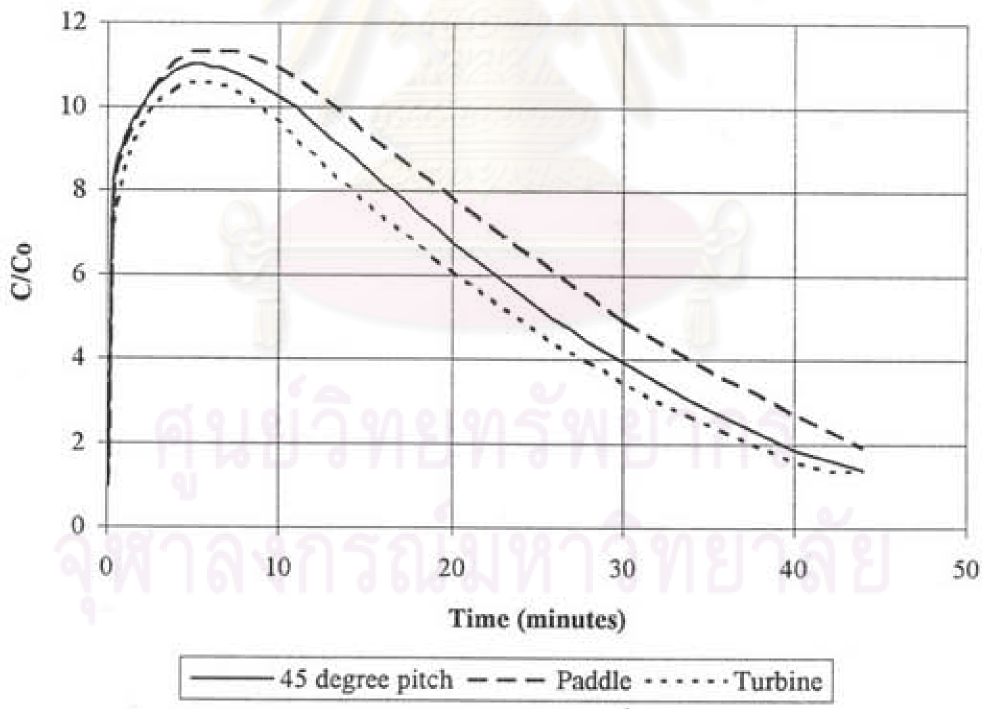
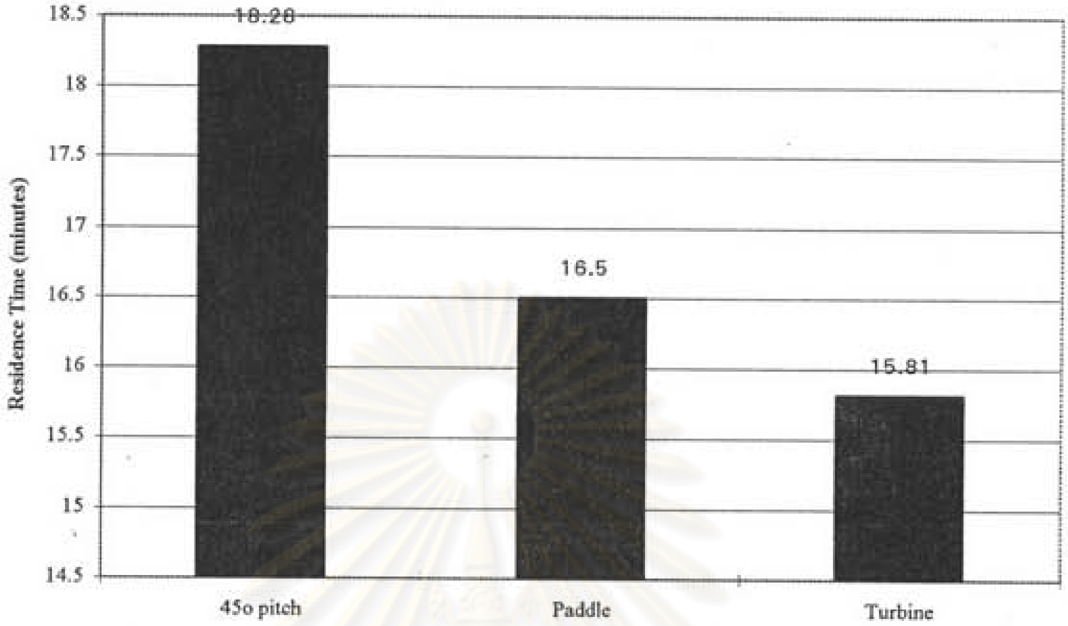


Figure 5.41 Comparison between the types of impeller at 1/3 of the tank diameter above the bottom (441.57 rpm.) in 20 cm. tank diameter (the mean residence time 30 minutes)



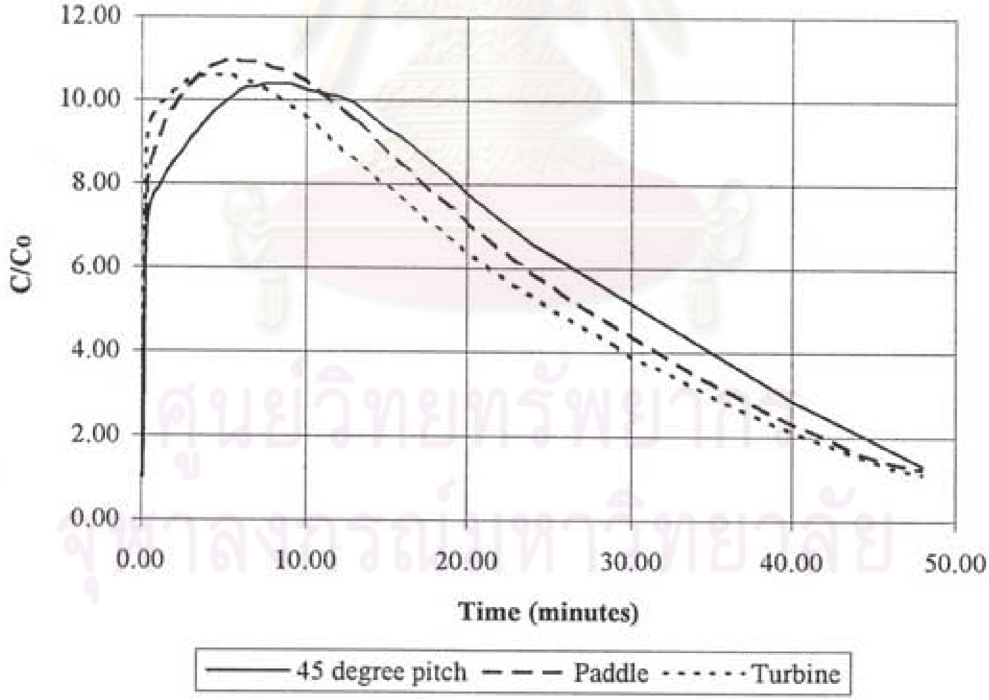


Figure 5.42 Comparison between the types of impeller at 1/3 of the tank diameter above the bottom (618.27 rpm.) in 20 cm. tank diameter (the mean residence time 30 minutes)

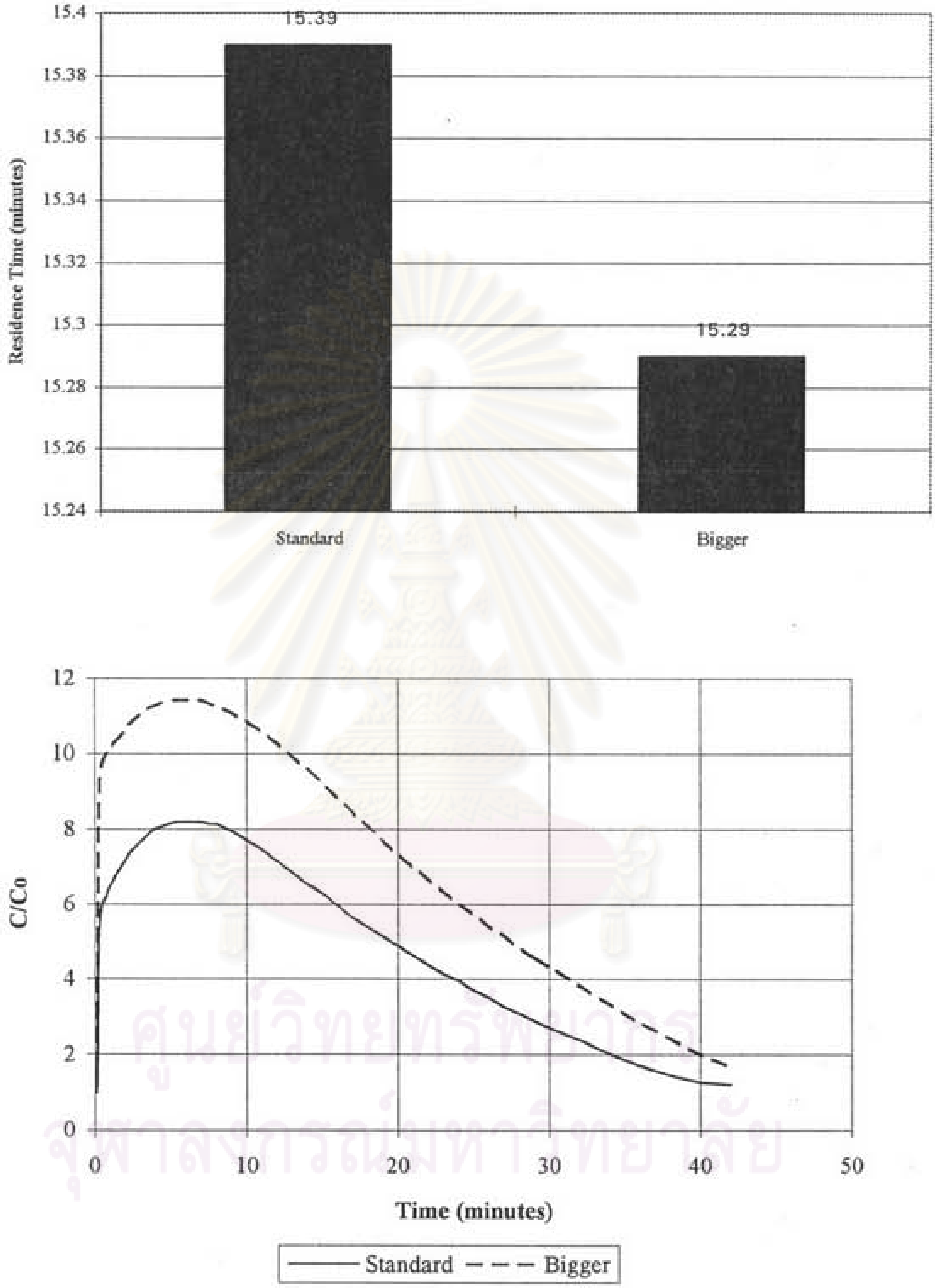
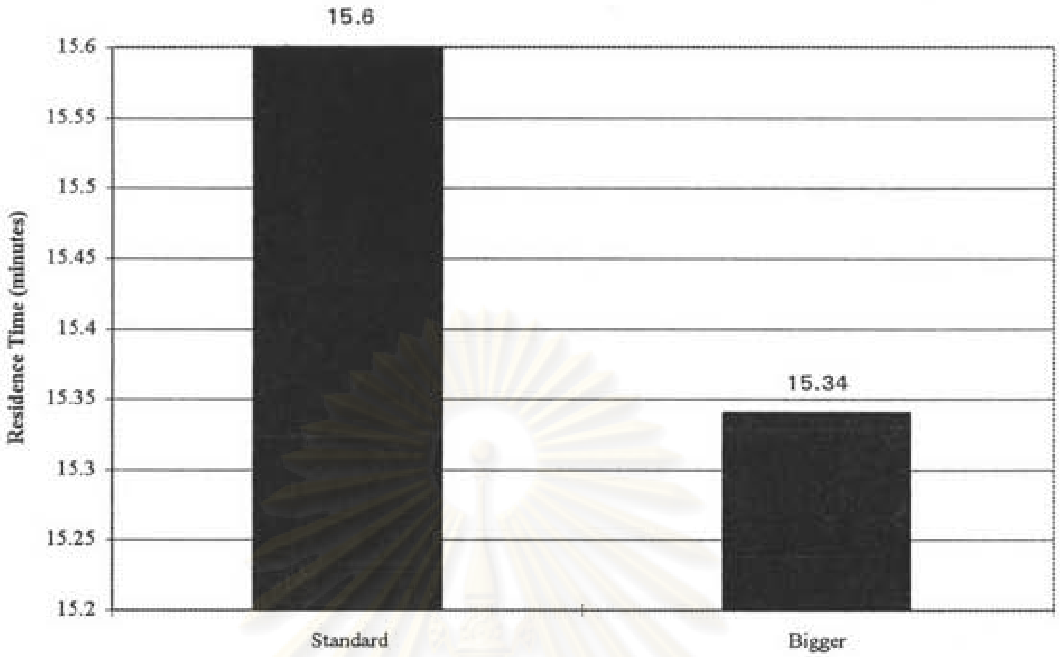


Figure 5.43 Comparison between the size impeller at 1/3 of the tank diameter above the bottom with speed 264.87 rpm. in 20 cm. tank diameter (the mean residence time 30 minutes)



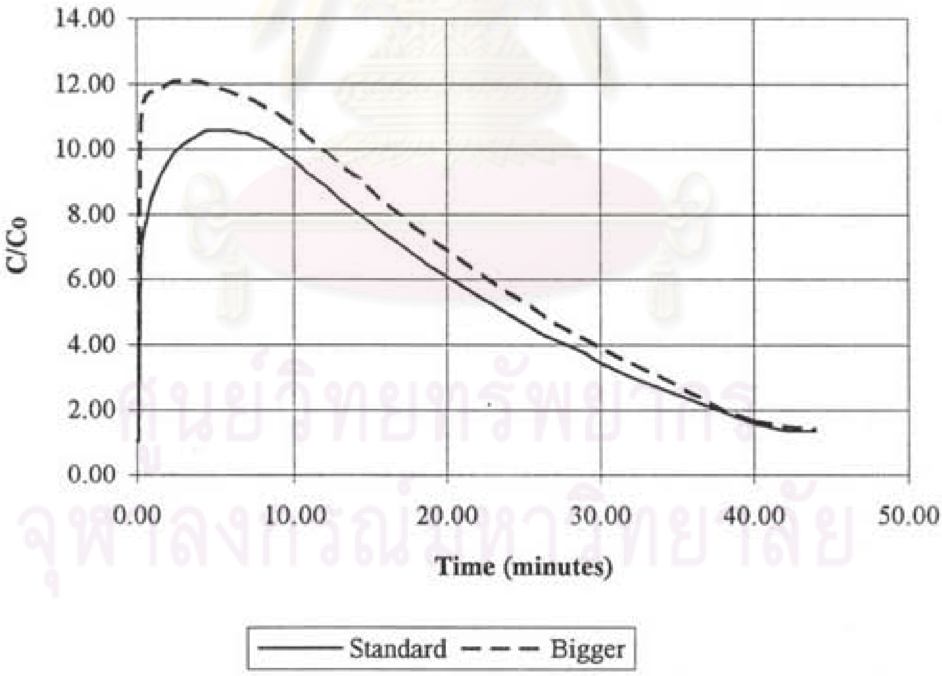
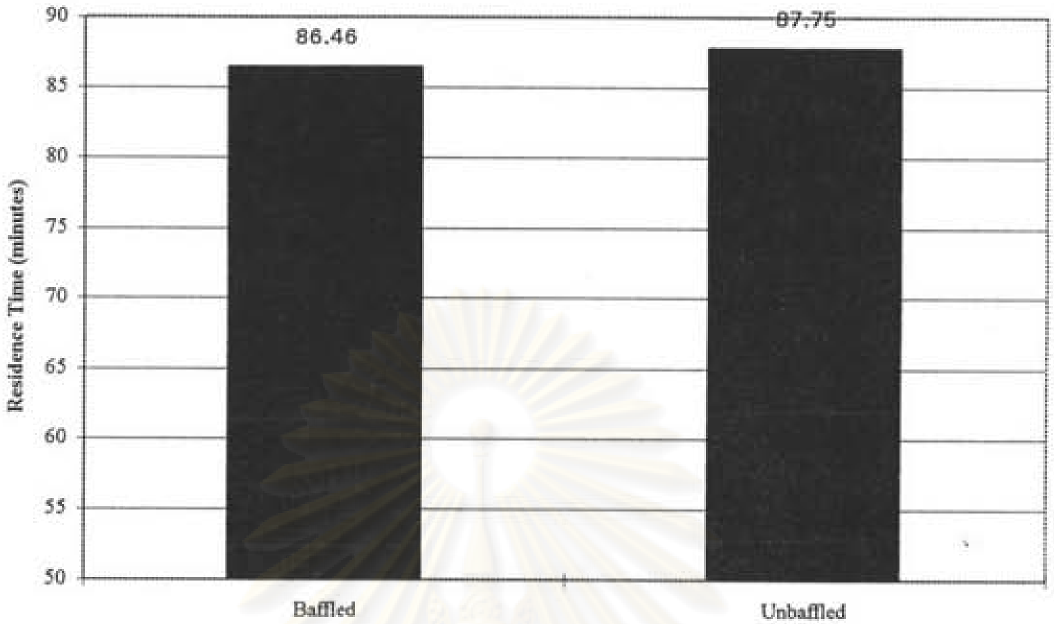


Figure 5.44 Comparison between the size impeller at 1/3 of the tank diameter above the bottom with speed 441.57 rpm. in 20 cm. tank diameter (the mean residence time 30 minutes)



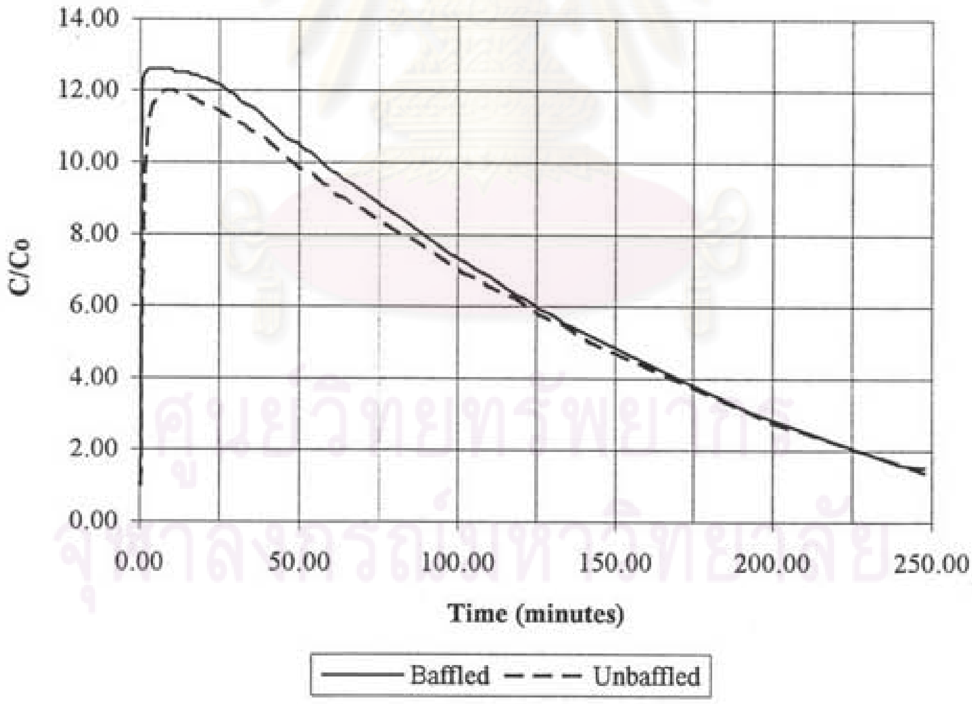


Figure 5.45 Comparison between the baffled and unbaffled system in 30 cm. tank diameter (the mean residence time 187.77 minutes)

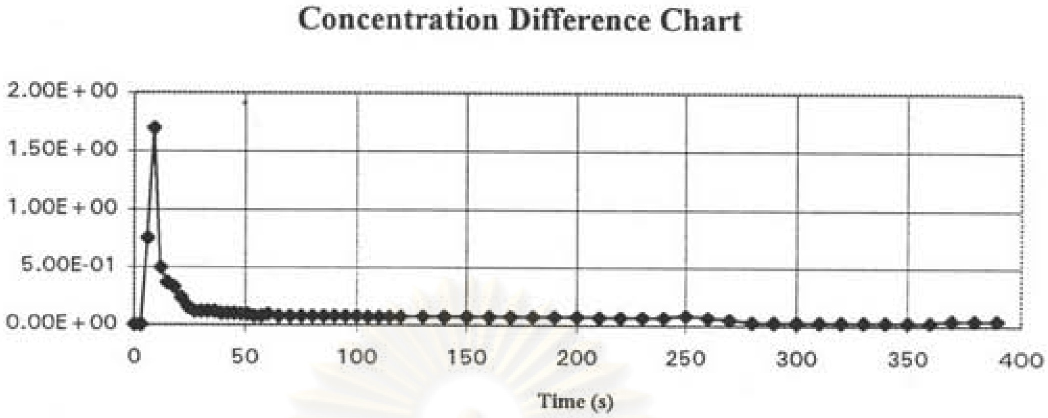


Figure 5.46 Concentration Difference Chart using turbine at 1/3 of 20 cm. Tank (mean residence time 55 min. and rotation speed 264.87 rpm.)

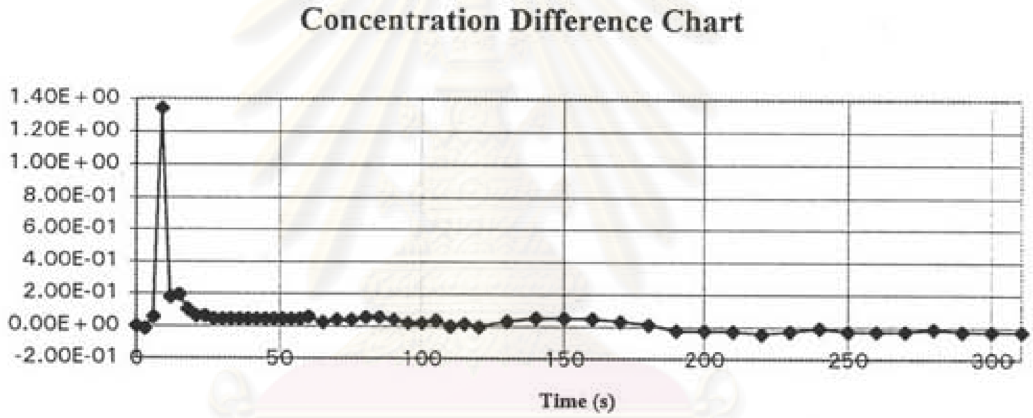


Figure 5.47 Concentration Difference Chart using turbine at 1/3 of 20 cm. Tank (mean residence time 55 min. and rotation speed 441.57 rpm.)

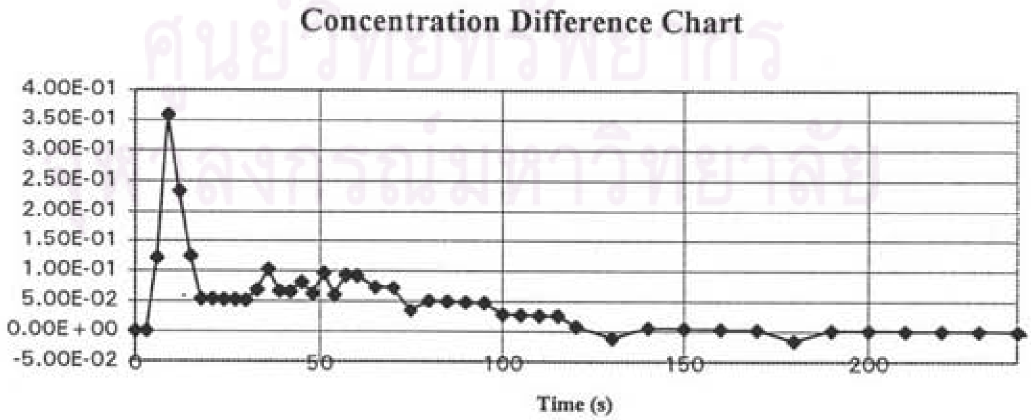


Figure 5.48 Concentration Difference Chart using turbine at 1/3 of 20 cm. Tank (mean residence time 55 min. and rotation speed 618.27 rpm.)

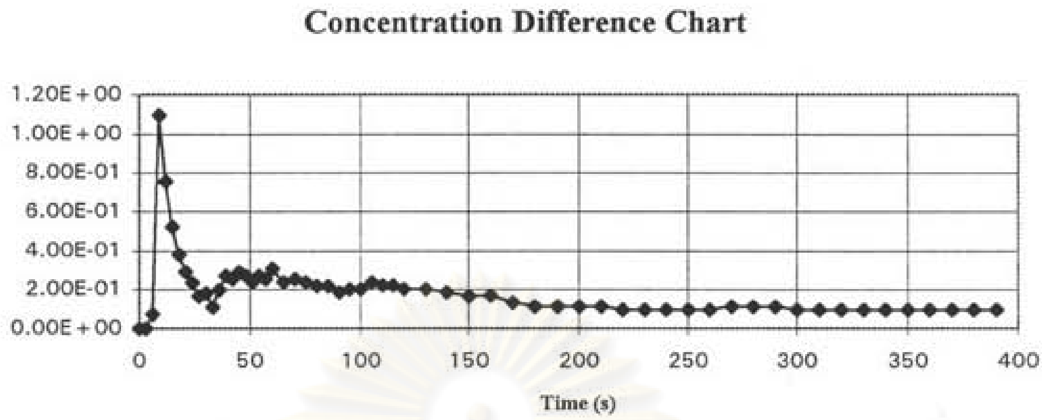


Figure 5.49 Concentration Difference Chart using paddle at 1/3 of 20 cm. Tank (mean residence time 55 min. and rotation speed 264.87 rpm.)

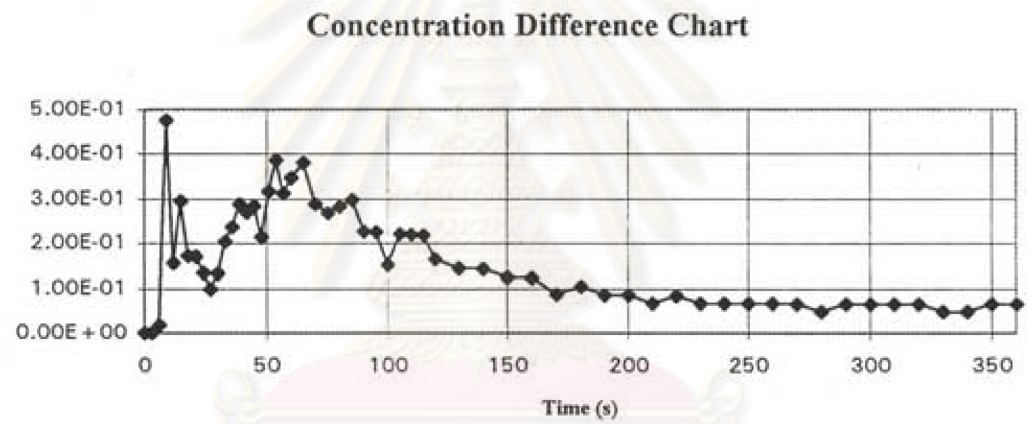


Figure 5.50 Concentration Difference Chart using 45° pitch at 1/3 of 20 cm. Tank (mean residence time 55 min. and rotation speed 264.87 rpm. CCW.)

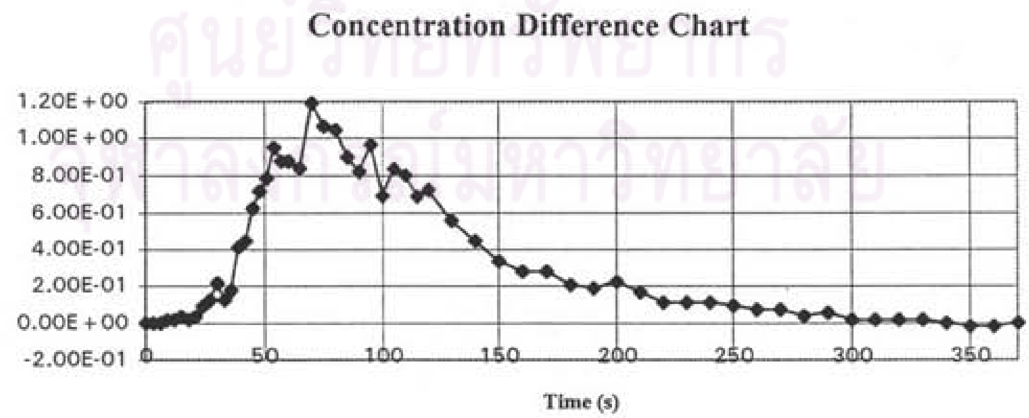


Figure 5.51 Concentration Difference Chart using 45° pitch at 1/3 of 20 cm. Tank (mean residence time 55 min. and rotation speed 264.87 rpm. CW.)

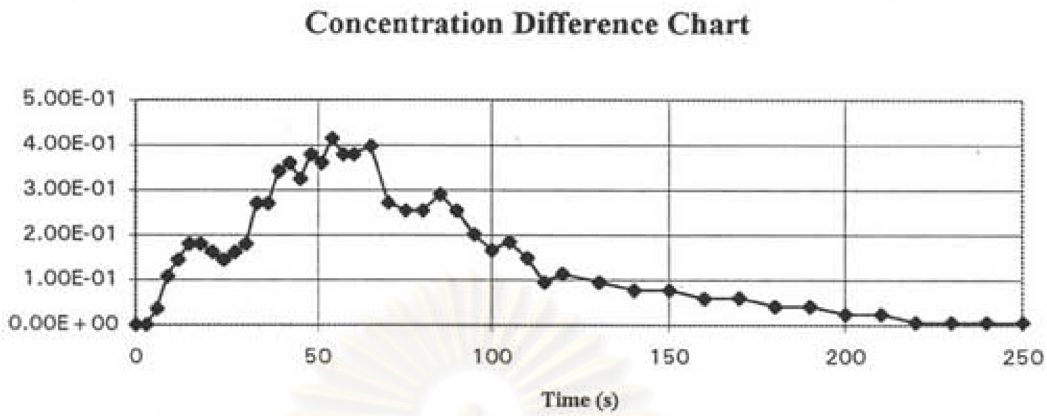


Figure 5.52 Concentration Difference Chart using 45° pitch at 1/3 of 20 cm. Tank (mean residence time 55 min. and rotation speed 618.27 rpm. CW.)

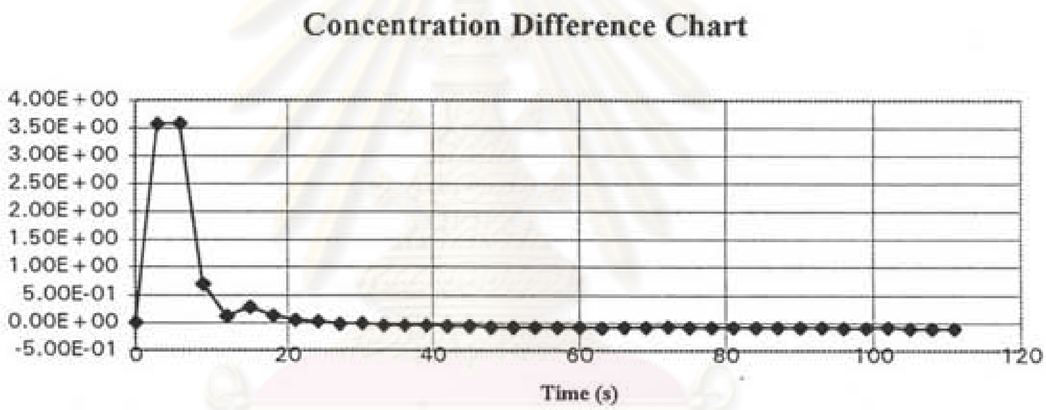


Figure 5.53 Concentration Difference Chart using turbine at 1/3 of 20 cm. Tank (mean residence time 30 min. and rotation speed 264.87 rpm.)

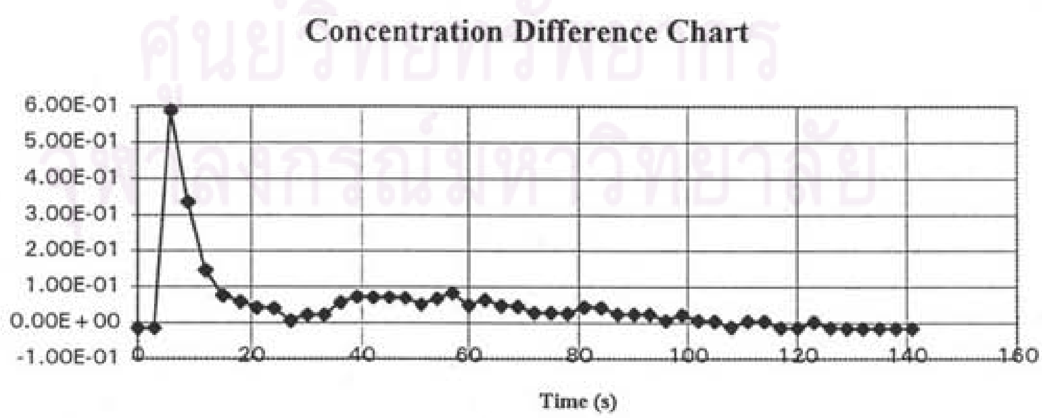


Figure 5.54 Concentration Difference Chart using turbine at 1/3 of 20 cm. Tank (mean residence time 30 min. and rotation speed 618.27 rpm.)

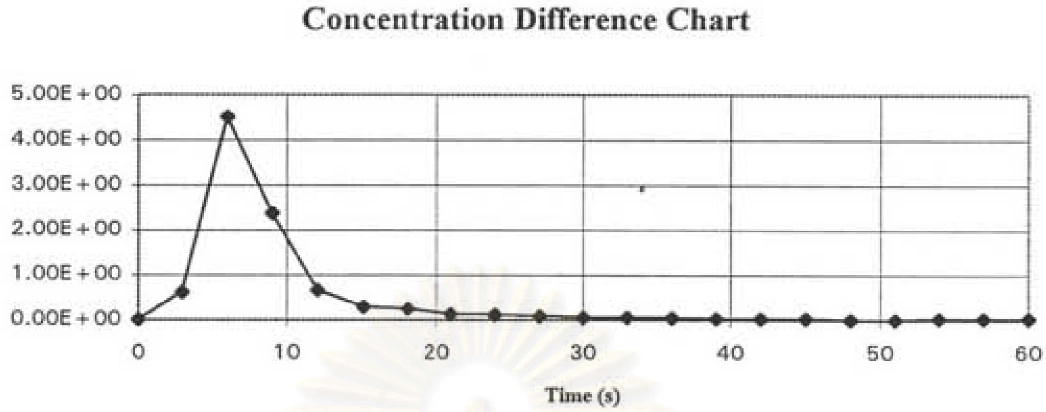


Figure 5.55 Concentration Difference Chart using turbine at 1/2 of 20 cm. Tank (mean residence time 30 min. and rotation speed 264.87 rpm.)

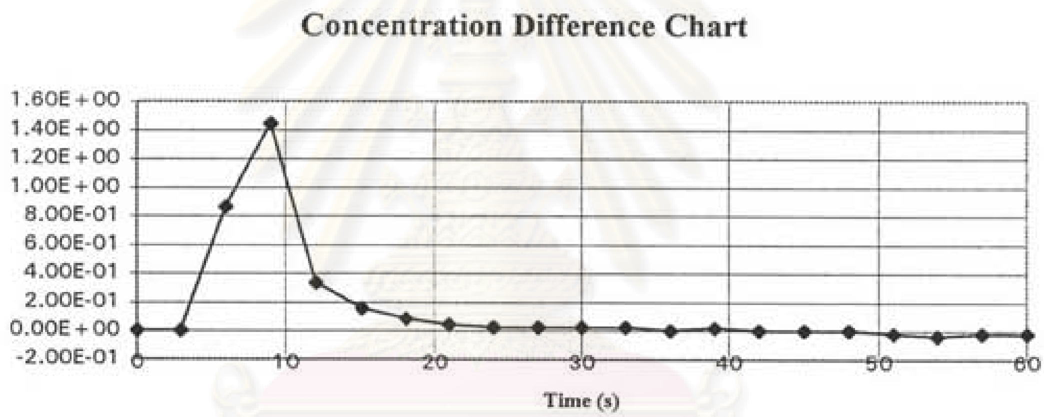


Figure 5.56 Concentration Difference Chart using turbine at 1/2 of 20 cm. Tank (mean residence time 30 min. and rotation speed 441.57 rpm.)

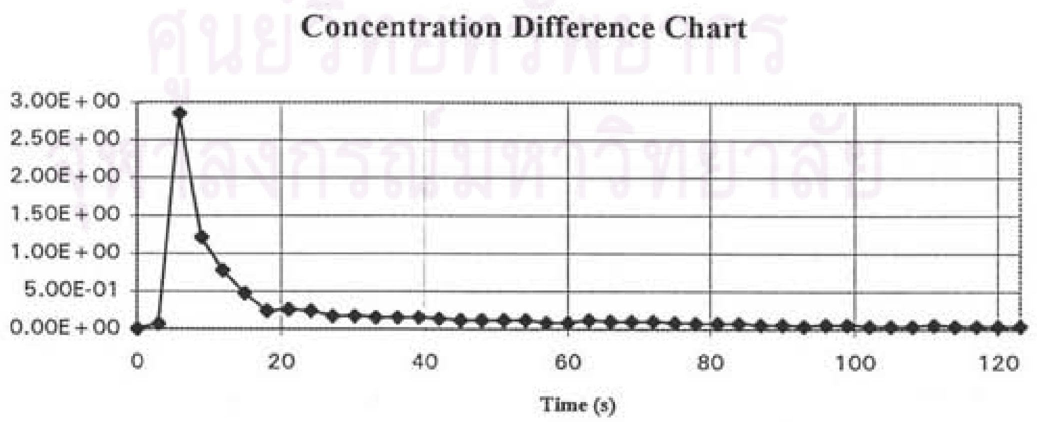


Figure 5.57 Concentration Difference Chart using paddle at 1/3 of 20 cm. Tank (mean residence time 30 min. and rotation speed 264.87 rpm.)

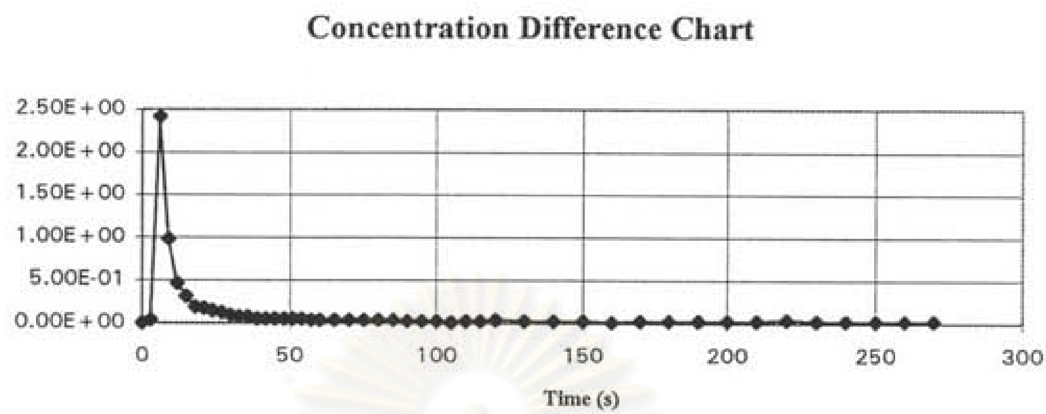


Figure 5.58 Concentration Difference Chart using paddle at 1/3 of 20 cm. Tank (mean residence time 30 min. and rotation speed 441.57 rpm.)

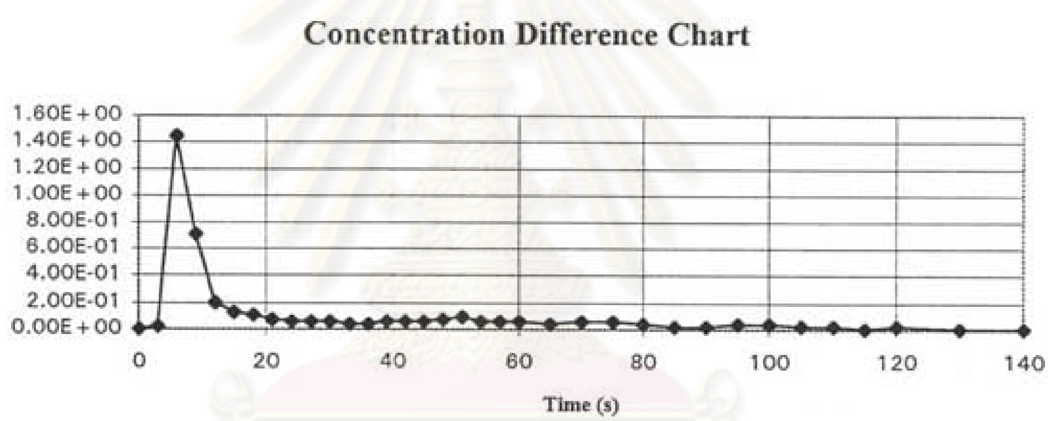


Figure 5.59 Concentration Difference Chart using paddle at 1/3 of 20 cm. Tank (mean residence time 30 min. and rotation speed 618.27 rpm.)

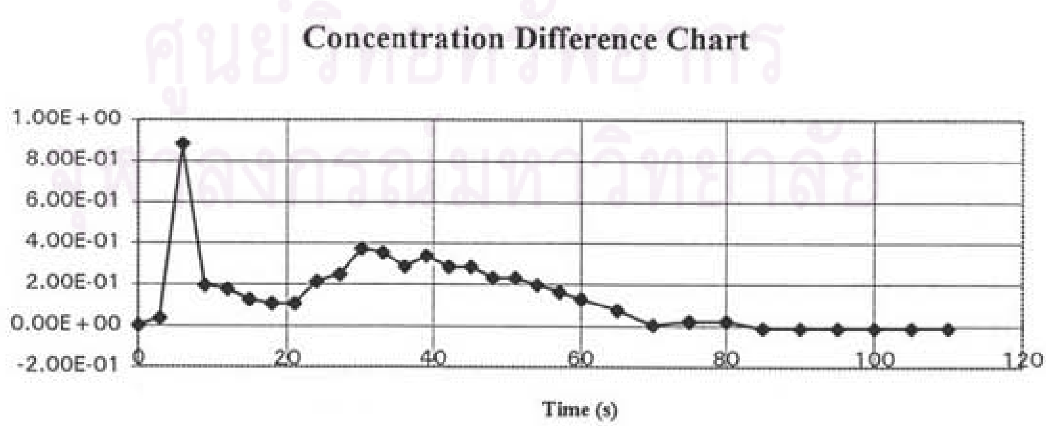


Figure 5.60 Concentration Difference Chart using big turbine at 1/3 of 20 cm. Tank (mean residence time 30 min. and rotation speed 264.87 rpm.)

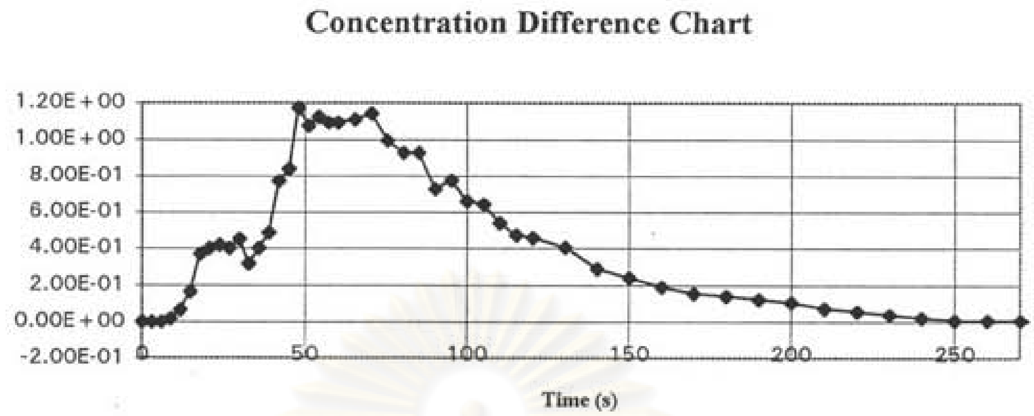


Figure 5.61 Concentration Difference Chart using 45° pitch at 1/3 of 20 cm. Tank (mean residence time 30 min. and rotation speed 264.87 rpm. CW.)

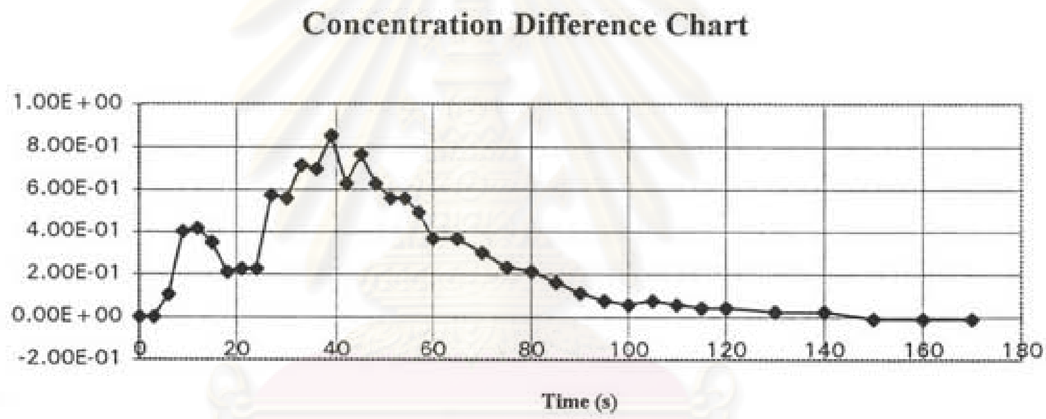


Figure 5.62 Concentration Difference Chart using 45° pitch at 1/3 of 20 cm. Tank (mean residence time 30 min. and rotation speed 618.27 rpm. CW.)

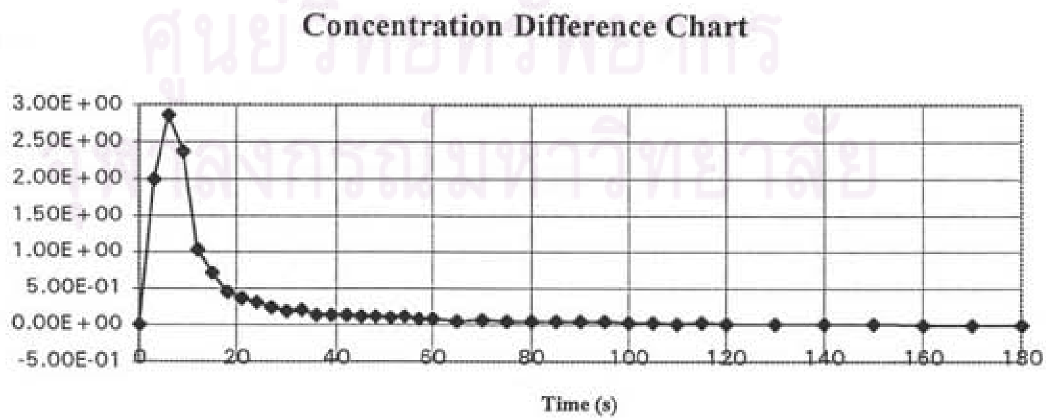


Figure 5.63 Concentration Difference Chart using paddle at 1/2 of 20 cm. Tank (mean residence time 30 min. and rotation speed 264.87 rpm.)

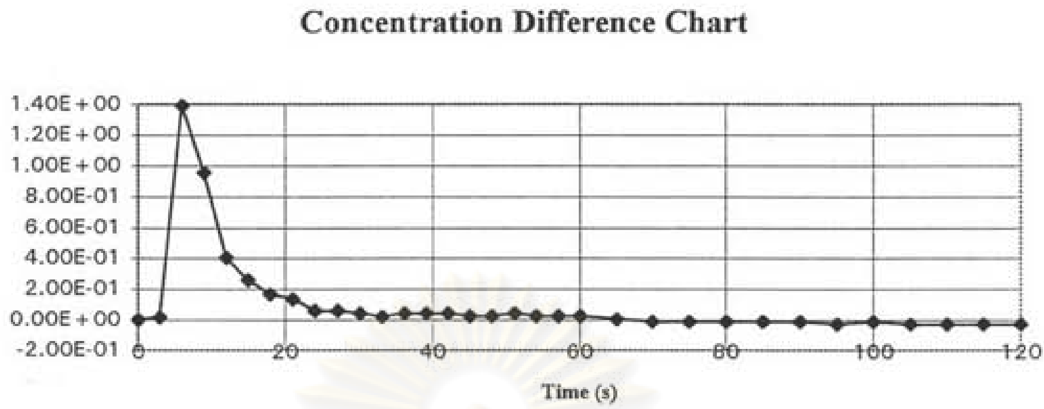


Figure 5.64 Concentration Difference Chart using paddle at 1/2 of 20 cm. Tank (mean residence time 30 min. and rotation speed 441.57 rpm.)

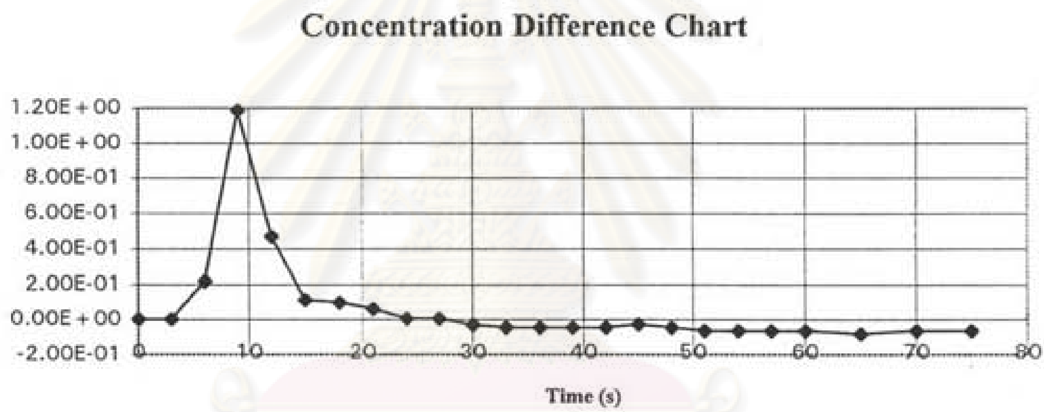


Figure 5.65 Concentration Difference Chart using paddle at 1/2 of 20 cm. Tank (mean residence time 30 min. and rotation speed 618.27 rpm.)

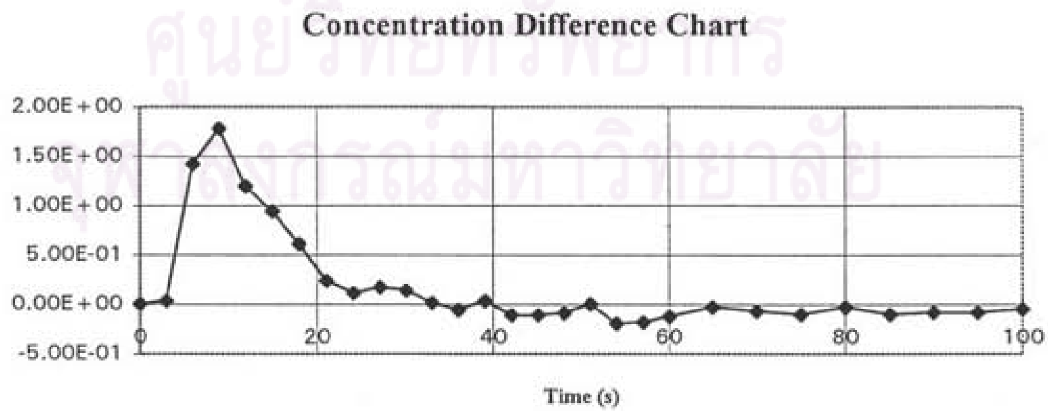


Figure 5.66 Concentration Difference Chart using 45° pitch at 1/2 of 20 cm. Tank (mean residence time 30 min. and rotation speed 441.57 rpm. CCW.)

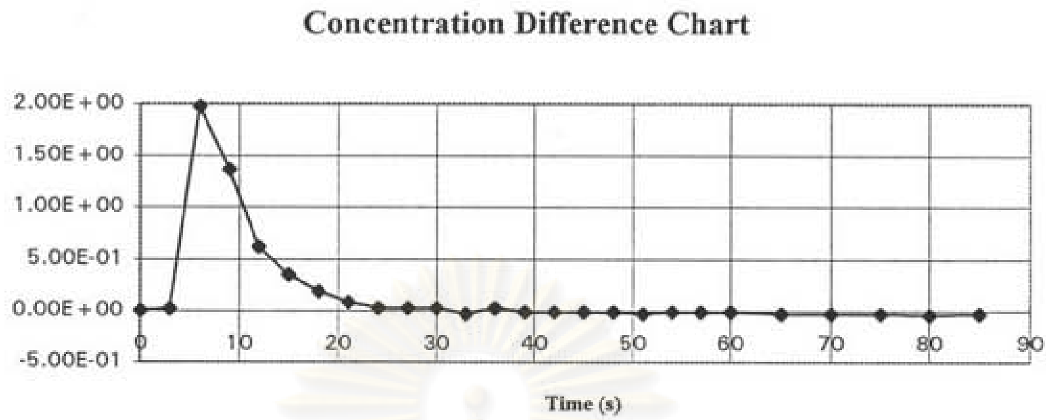


Figure 5.67 Concentration Difference Chart using 45° pitch at 1/2 of 20 cm. Tank (mean residence time 30 min. and rotation speed 618.27 rpm. CCW.)

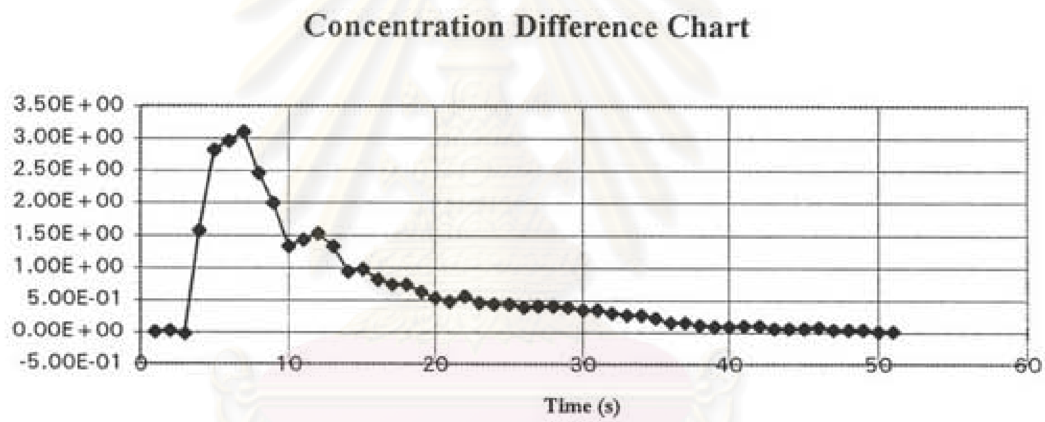


Figure 5.68 Concentration Difference Chart using 45° pitch at 1/2 of 20 cm. Tank (mean residence time 30 min. and rotation speed 264.87 rpm. CW.)

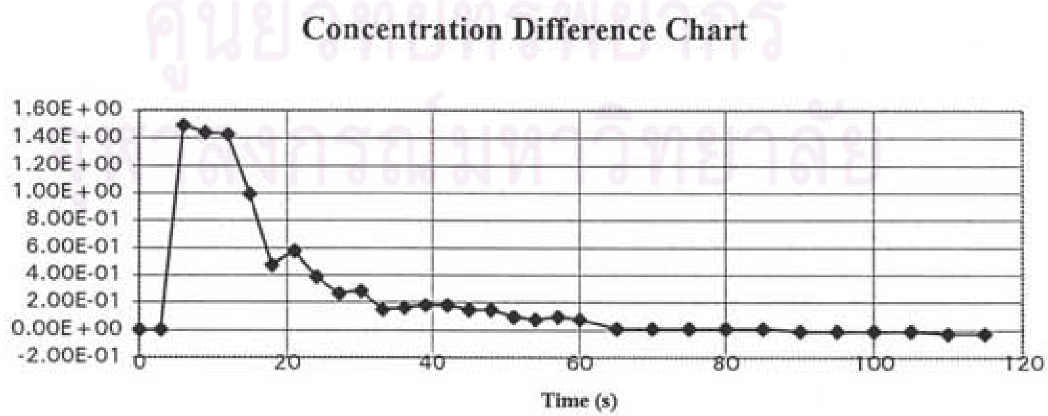


Figure 5.69 Concentration Difference Chart using 45° pitch at 1/2 of 20 cm. Tank (mean residence time 30 min. and rotation speed 618.27 rpm. CW.)

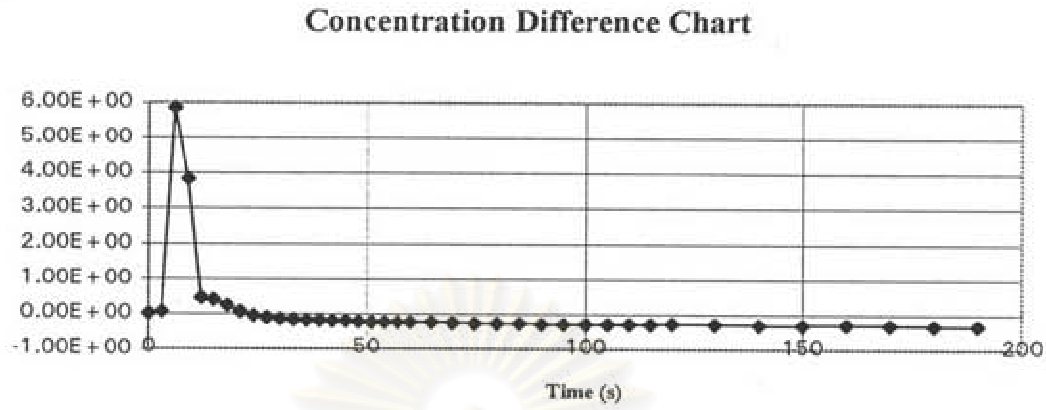


Figure 5.70 Concentration Difference Chart using turbine at 1/3 of 20 cm. Tank (mean residence time 15 min. and rotation speed 264.87 rpm.)

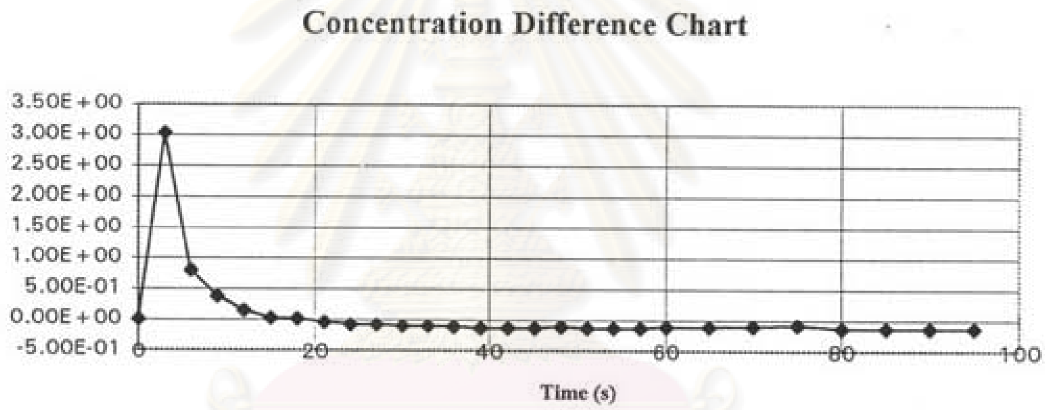


Figure 5.71 Concentration Difference Chart using turbine at 1/3 of 20 cm. Tank (mean residence time 15 min. and rotation speed 441.57 rpm.)

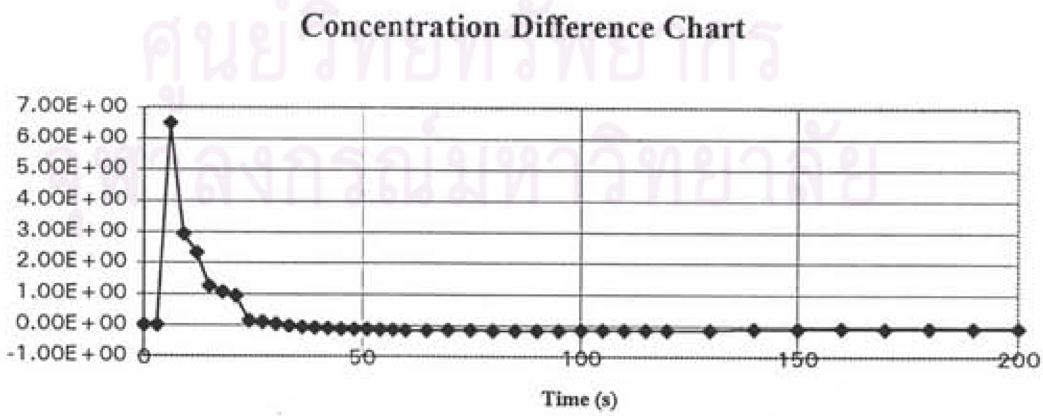


Figure 5.72 Concentration Difference Chart using paddle at 1/3 of 20 cm. Tank (mean residence time 15 min. and rotation speed 264.87 rpm.)

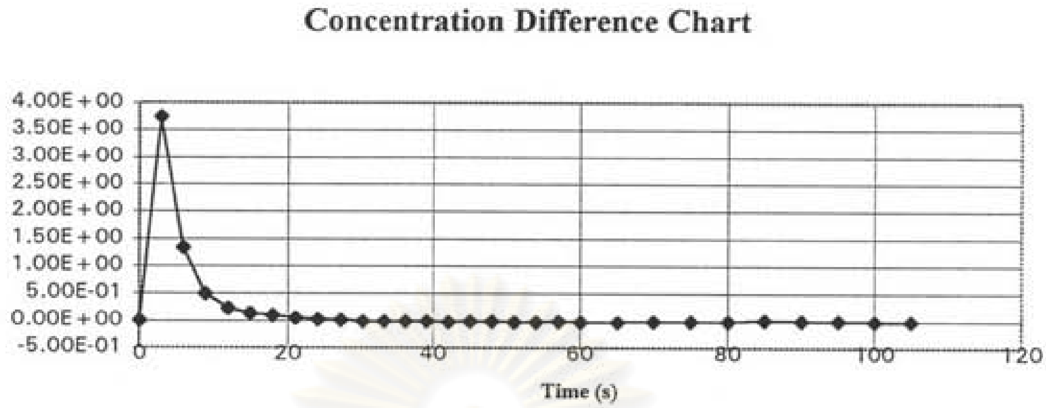


Figure 5.73 Concentration Difference Chart using paddle at 1/3 of 20 cm. Tank (mean residence time 15 min. and rotation speed 618.27 rpm.)

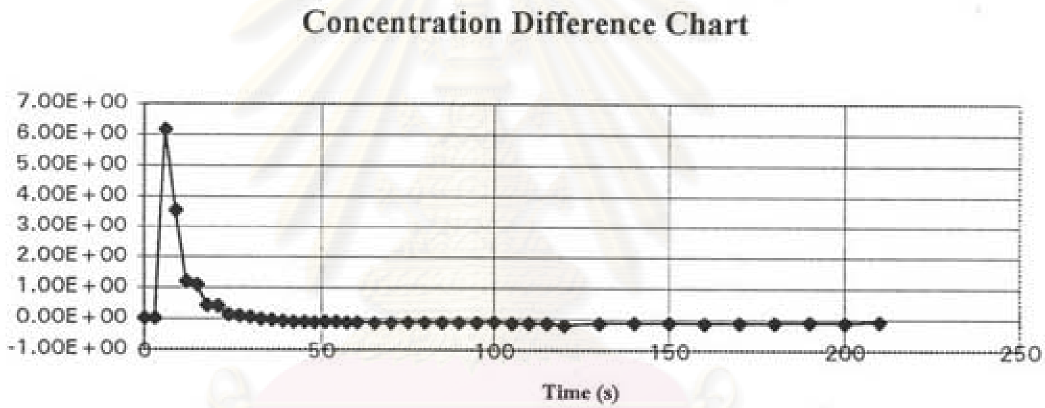


Figure 5.74 Concentration Difference Chart using 45° pitch at 1/3 of 20 cm. Tank (mean residence time 15 min. and rotation speed 264.87 rpm. CCW.)

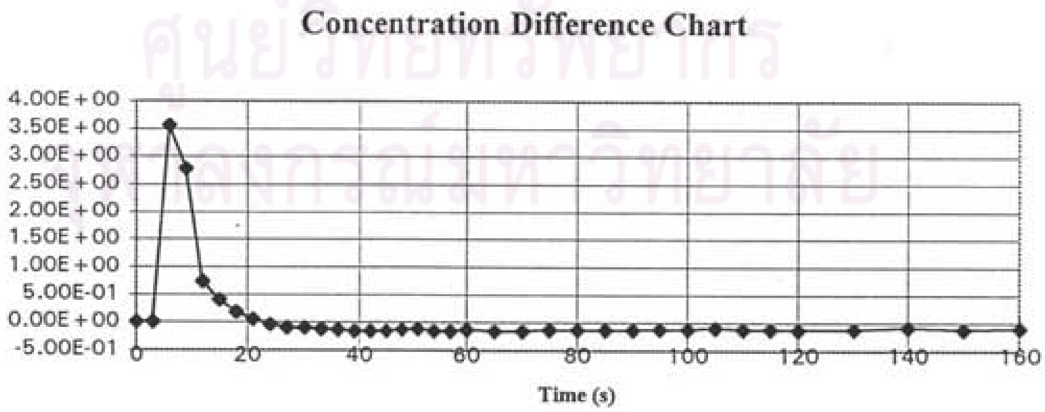


Figure 5.75 Concentration Difference Chart using 45° pitch at 1/3 of 20 cm. Tank (mean residence time 15 min. and rotation speed 441.57 rpm. CCW.)

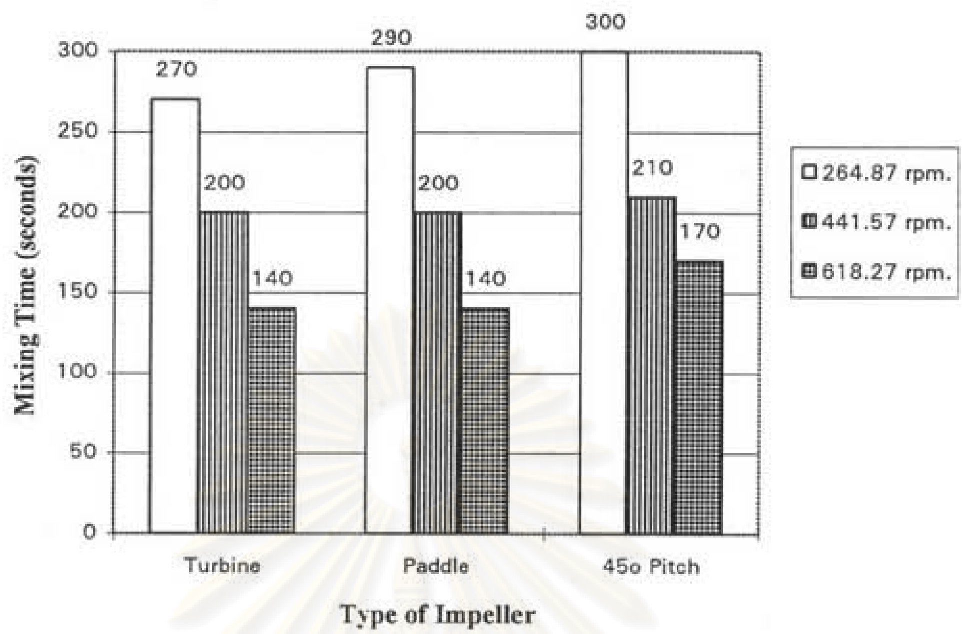


Figure 5.76 Mixing time comparison chart at different rotational speeds of the impeller

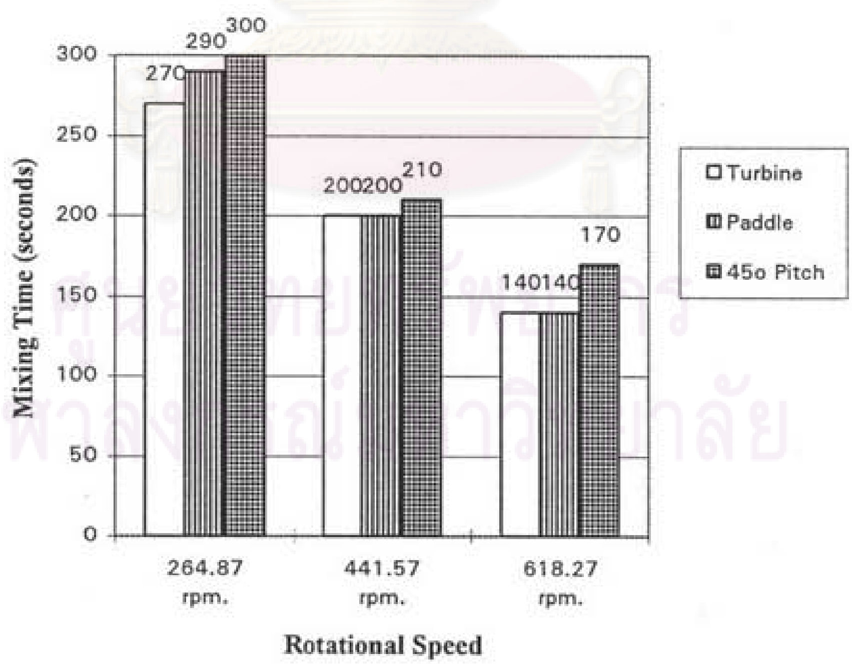


Figure 5.77 Mixing time comparison chart at different types of the impellers

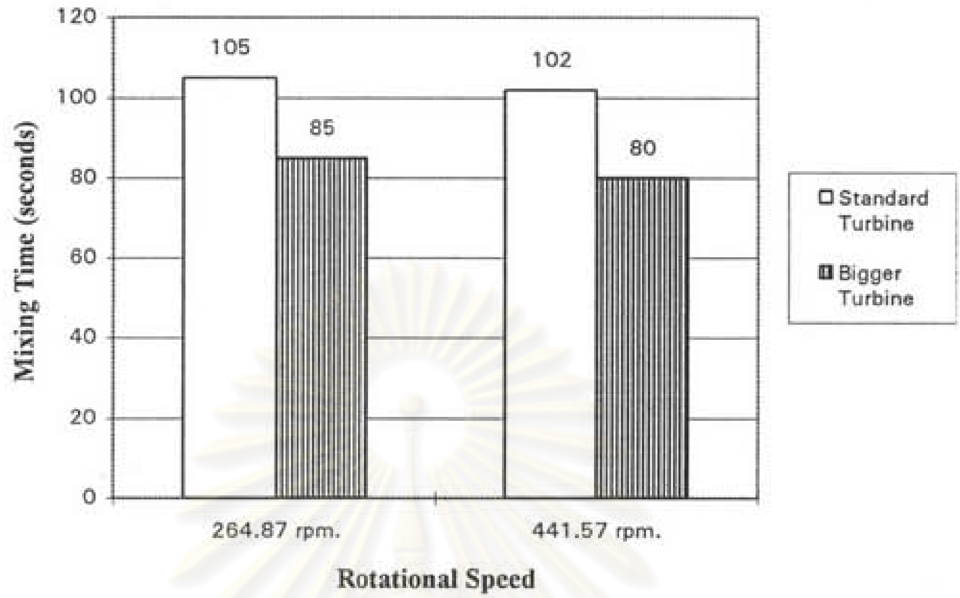


Figure 5.78 Mixing time comparison chart at different sizes of the impeller

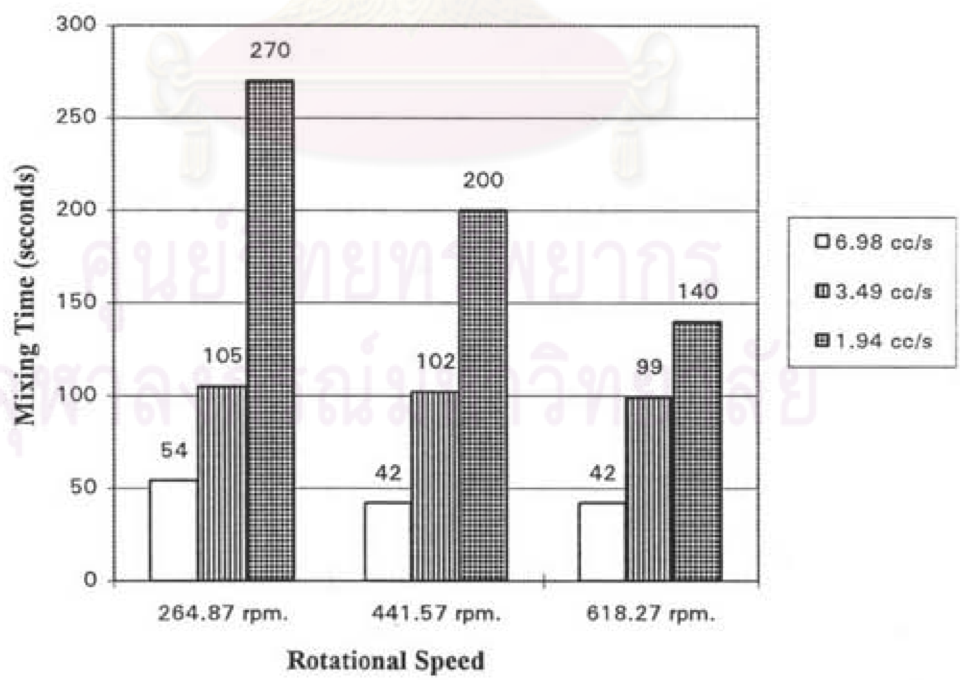


Figure 5.79 Mixing time comparison chart at different inlet flow rates

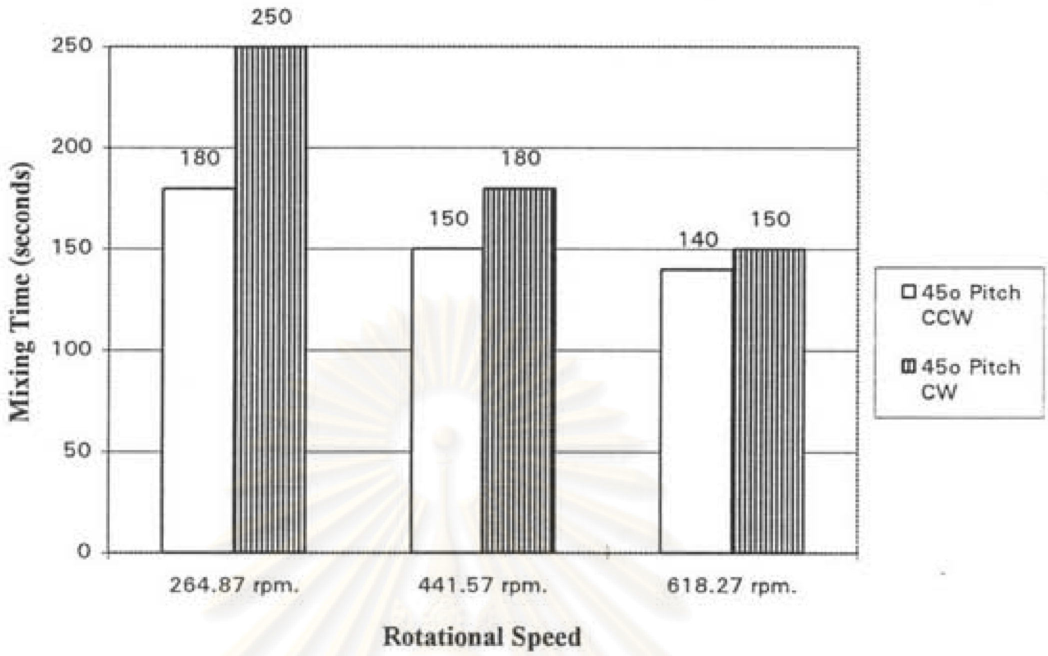


Figure 5.80 Mixing time comparison chart at different directions of the impeller rotations