

CHAPTER III  
LITERATURE REVIEW



3.1 General Background

Biological treatment is mainly classified into two processes, aerobic and anaerobic. The aerobic treatment process is separated into many processes for instance, activated sludge, trickling filter, aerated lagoon etc. The activated sludge process was developed in England during the early year 1900, GOODMAN and ENGLAND (1974). After that, many modifications of the original process have been developed. A modification that has been extensively use is the contact stabilization process.

Contact stabilization process was first investigated in England by COOMBS (1921) and later in the U.S.A. by ULLRICH and SMITH (1951). The process was first named "Biosorption" by ULLRICH and SMITH (1951) due to the rapid substrate removal when activated sludge was mixed with wastewater in contact tank. The use of a contact stabilization in place of a conventional flow scheme greatly increases volumetric loading capacity without decreasing process efficiency. This was accomplished at Austin, Texas, a 6 MGD conventional activated sludge plant was upgraded to treat 16 MGD in a contact stabilization mode without the bulking problems encountered prior to modification, ULLRICH and SMITH (1957).

Although this process was developed many decade years ago, however, the principles of substrate removal mechanisms, the methods of design calculation have not been clearly concluded.

### 3.2 Description of Contact Stabilization Process

The contact stabilization process is known in various names, biosorption, bioflocculation, two stages aeration and sludge reaeration. This process was modified from conventional activated sludge system. The process flow diagram is shown in Fig. 3.1.

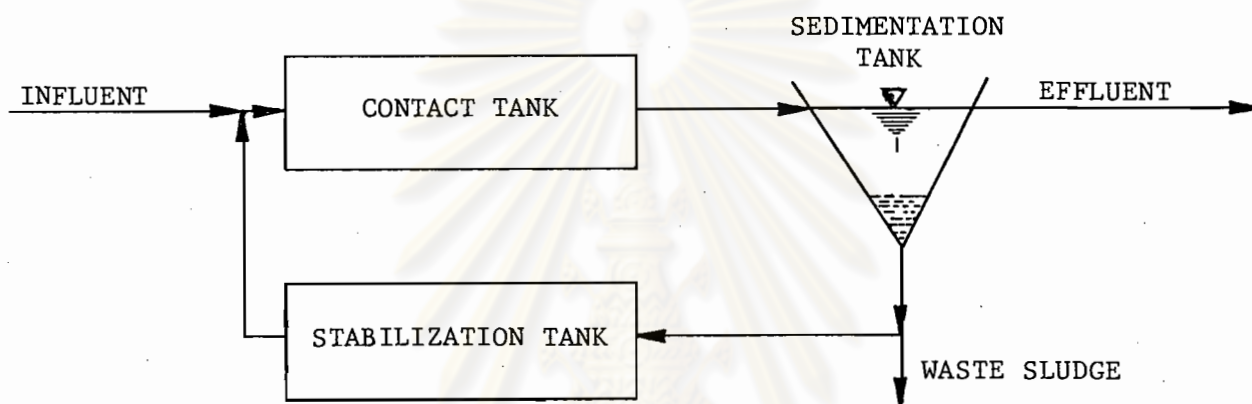


Fig. 3.1 - Flow Diagram of Contact Stabilization Process

Contact stabilization process differs from conventional activated sludge system according to the number of aeration tanks. The former has two aeration tanks between sedimentation tank while the latter has only single tank.

The influent wastewater is mixed with returned activated sludge in the contact tank (1<sup>st</sup> aeration tank), normally 30 to 90 minutes detention time. After the contact period, the mixed liquor activated sludge is allowed to settle in the sedimentation tank for a solid - liquid separation.

A small portion of settled sludge is wasted while the remainder flows to the stabilization tank (2<sup>nd</sup> aeration tank) for a period of time,

generally 3-6 hours, then the stabilized sludge is returned to the contact tank to be mixed with influent wastewater again.

### 3.3 Development and Application of the Process

The contact stabilization process was firstly investigated in England by COOMBS(1921). According to CHASE (1944), a contact stabilization wastewater treatment plant was built in 1930 at Birmingham, England, with one hour and eight hour contact time and stabilization time respectively.

MALLORY patented a process in 1948. This process was similar to the contact stabilization process, illustrated in Fig. 3.2.

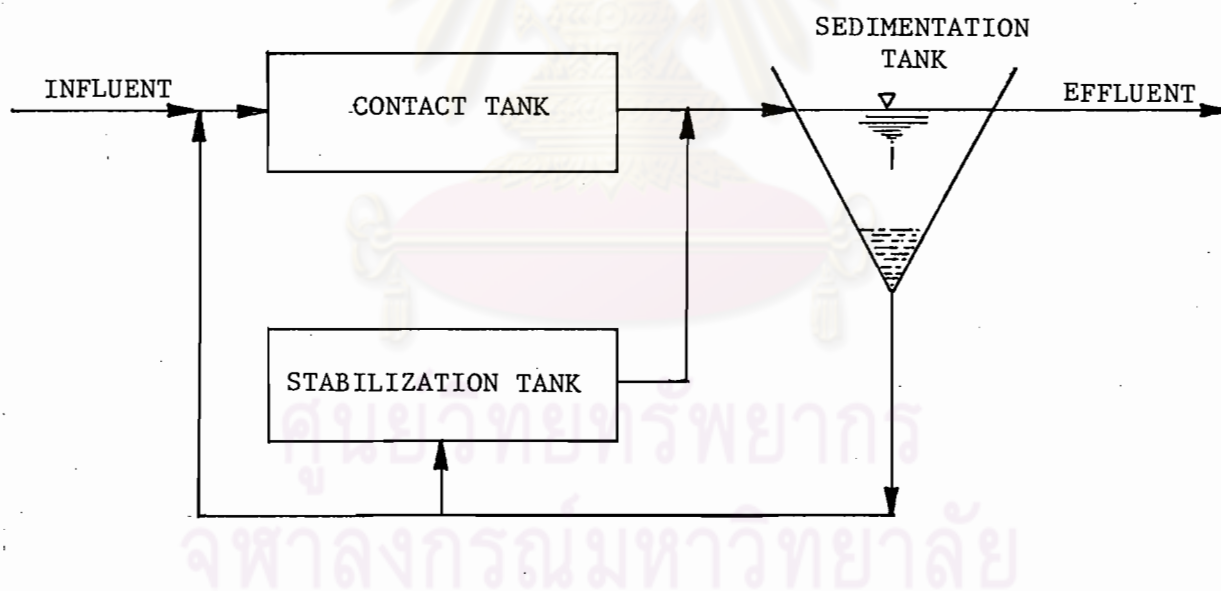


Fig. 3.2 - Wastewater Treatment Process Flow Diagram Patented by MALLORY (Reported by THIRUMURTHI, 1977)

In Fig. 3.2 the settled sludge from a sedimentation tank is pumped to stabilization tank which a portion of it is bypassed to be mixed with influent wastewater in a contact tank. Then the outlet from the contact tank and the stabilization one enter the sedimentation tank

making the process in closed circuit.

ULLRICH and SMITH (1951, 1957) faced serious problems of overloaded and bulking sludge in Austin, Texas, treatment plant. The laboratory study and pilot plant one were conducted in Austin. ULLRICH and SMITH solved the problems by modifying the existing conventional activated sludge process into the process which they initially termed "Biosorption Process". This biosorption plant had an ability to increase a capacity from 6 MGD to 16 MGD without addition of a aeration tank capacity and still gave high BOD and SS removal. The problem of sludge bulking was eliminated and the control operation was also rendered easier and simpler than before.

BOON (1969) indicated that in both plants of contact stabilization and conventional activated sludge the greatest proportion of the BOD of the settled sewage was removed within the first 15 min. of aeration with activated sludge. He also reported that, SIDDIQI et al. (1966) postulated that the loss of substrate removal capacity of activated sludge after a prolonged period of stabilization was due to inactivation or loss of previously induced enzyme systems. BOON concluded that in order to obtain optimum performance from a contact stabilization process a careful balance would have to be made between the periods of contact and stabilization. The optimum periods of retention would depend on the composition of the wastewater and on the degree of purification required.

BERRYHILL et al. (1970) conducted an experimental investigation of two laboratory scale units to compare the performance of a contact stabilization process with that of a high rate activated sludge process.

The results indicated that the high-rate process produced a slightly better effluent than the contact stabilization process. The variations in the ratios of the concentrations of soluble and total substrate should be considered in design of contact stabilization units.

GUJER and JENKINS (1975 a,b) presented kinetic models of a contact stabilization process by experimental verification of bench-scale units treating settled domestic sewage. The models were generated based on the concept of oxygen equivalence mass balance. Various parameters and informations were observed such as, process loading (substrate removal rate), temperature, distribution of microorganisms in both tanks, sludge production, oxygen uptake rate, organic nitrogen conversion, nitrification and effluent suspended solids. They concluded that process loading, temperature, distribution of microorganisms in both tanks and recycle ratio were independent parameters in the design of contact stabilization process. This resulted to increase the design flexibility comparable with conventional activated sludge process which had only two independent variables of process loading and the temperature.

BENEFIELD & RANDALL (1976) developed design equations for contact stabilization process using concepts promulgated by ECKENFELDER (1970) and LAWRENCE and McCARTY (1970). He also presented a procedure for engineers to use these equations to apply in the design of a contact stabilization process. Nevertheless, the theoretical equations were developed by many assumptions without experimental data supported as discussed by ORHON (1977).

THRIRUMURTHI (1977) studied on the comparison of a high-rate activated sludge unit with an aeration tank volume equal to the combined

volumes of contact and reaeration tank of a contact stabilization process. The results postulated to previous investigator, BOON (1970), that both units produced an effluent of almost the same quality and had equal BOD or COD removal rate. The author also concluded that mild shocks induced by fluctuating hydraulic and organic loads were better absorbed by a single tank aeration process due to the greater volume than the contact tank.

ORHON and JENKINS (1977) modeled the contact stabilization process by assuming that substrate removal occurred only in the contact tank while only microbial decay or endogenous respiration was assumed to occur in the stabilization tank. Data were presented to indicate the direct interrelationship between the microbial decay coefficient for the stabilization tank and substrate removal rate for the contact tank. The model was presented to facilitate the upgrading of overloaded plants to the desired effluent quality by using varying portions of available aeration tanks.

KHARARJIAN and SHERRARD (1977) studied on the batch aerobic treatment on various concentration of colloidal waste. The result showed that the COD concentrations of the soluble and colloidal waste fractions generally decreased exponentially during the batch experiments with no increased in soluble COD attributable to release by sludge organisms as reported by MCKINNEY (1962). They finally concluded that not all colloidal wastewaters exhibited a rapid uptake, substantial release and final drop in the concentration of organic material as illustrated in Fig. 3.3, therefore it was no reason to specify the contact stabilization process to a wastewater contained colloidal organic matters.

SAIPHANICH (1978) studied on the theoretical and experimental of contact stabilization process in carbonaceous phase and nitrification. The domestic wastewater was used as the influent substrate for the system. The kinetic coefficients: growth yield, microorganism decay rate, maximum rate of substrate utilization, half velocity coefficient etc. were determined. His results showed that the maximum rate of total substrate utilization in the contact tank of contact stabilization process was about 5 times much more than the conventional activated sludge process. The half velocity coefficient of the contact tank correlated with the fraction of biomass in the contact tank and sludge age. The mathematical models of contact stabilization process were proposed and proved by experimental data as well as the methods of design calculation in both phases have been suggested.

YUE (1979) studied on the modelization of substrate metabolization in contact stabilization process within carbonaceous phase. The study of SAIPHANICH (1978) was discussed and extended. YUE modeled two mathematical models, first model explained the rate of change of microorganisms and the second one explained the rate of change of substrate utilization.

### 3.4 Substrate Removal Mechanism

Although the contact stabilization process has been employed for many decades, the substrate removal mechanism of the process has not been clearly concluded yet. The various concepts are summarized as following:

ULLRICH & SMITH (1951), initiated the "Biosorption" concept, He explained this concept based on the high capacity to adsorb and absorb both of suspended solids and dissolved organic matter by activated sludge

in the contact tank. The return sludge from sedimentation tank which contained the adsorbed and absorbed suspended and dissolved organic matter from the wastewater is conducted to stabilization tank where it is aerobically digested or reactivated in this tank.

ECKENFELDER and O'CONNOR (1961) reported that the BOD removal in contact aeration tank is achieved by absorption of organic matter and by stabilization (oxidation) in the reaeration tank. ECKENFELDER (1966) has illustrated the schematic diagram of substrate removal in contact stabilization process as shown in Fig. 3.4.

McKINNEY (1962) cited on the experimental of MANSEL SMITH of Austin, Texas, that there was an immediate drop in  $BOD_5$ , followed by a rise and then a second and final drop when we aerated a raw wastewater - activated sludge mixture under batch condition as shown in Fig. 3.3. From this type of phenomena the basis for two aeration basins was formed. In the first aeration basin, absorption of the colloidal organics was speculated to occur on the activated sludge floc particles. Because this phenomenon was observed to occur quickly, a short aeration basin contact time was used. The release of  $BOD_5$  and subsequent utilization by microorganisms then could occur in a second aeration basin of longer hydraulic detention time. Nevertheless, McKINNEY believed that microorganisms could continuously remove organic matter from wastewater by only one method, synthesis into new protoplasm. It was possible for the microorganisms to absorb large quantities of organic matter onto their cell surfaces but unless this organic matter was assimilated into protoplasm, the rate of absorption would approach zero. Since a definite quantity of organic matter was required to form the building blocks for the microbial cells and a



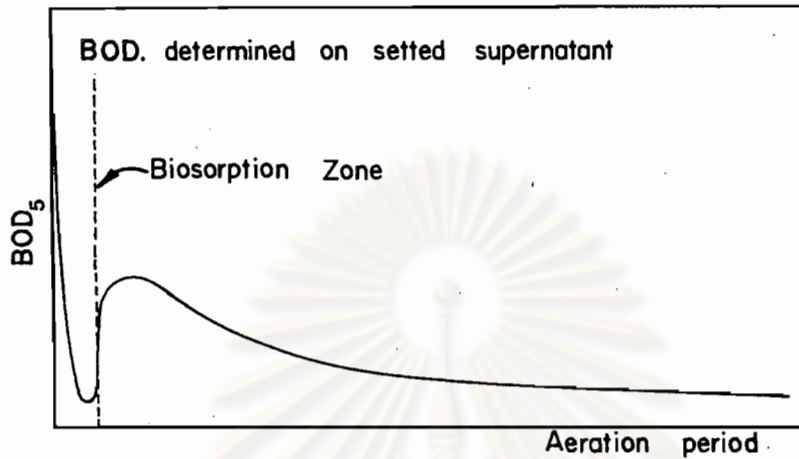


Fig. 3.3 Variation of BOD<sub>5</sub> of Raw Wastewater-Activated Sludge Mixture with Aeration Period ( McKINNEY , 1962 )

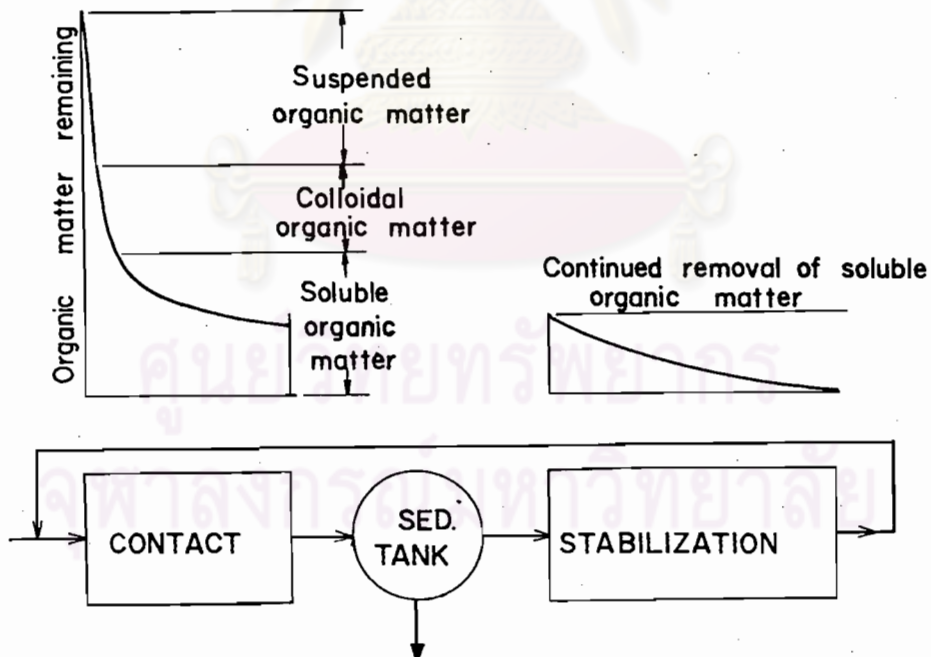


Fig. 3.4 Schematic Diagram of Substrate Removal in Contact Stabilization Process ( ECKENFELDER , 1966 )

definite quantity of organic matter must be oxidized to form the energy necessary for synthesis.

BANERJI et al. (1966) conducted batch experiments to study the mechanism of starch removal by activated sludge. They concluded that partial adsorption occurred and was dependent on temperature and acclimation. Adsorbed starch is degraded by cell-wall associated enzyme systems into smaller molecules. The remaining portion of the starch is either adsorbed on the cellular site vacated by the degraded starch molecules or degraded by small amounts of extracellular enzymes in the wastewater.

SIDDIQI et al. (1966) studied on the role of enzymes in the contact stabilization process. The research have shown the substantial significance and role of enzymes in the rapid removal of soluble organic matter in biological treatment. The data showed that enzymatic processes were particularly significant in substrate removal as opposed to the widely accepted surface removal phenomena.

JONES (1967) cited by THIRUMURTHI, 1977, proposed that during stabilization period the organisms released proteolytic enzymes to hydrolyze the particulate nutrient matter adsorbed in the contact tank. The hydrolyzed matter was then synthesized to new cells and at higher aeration periods quoted six hours, these cells entered the endogeneous respiration phase. At the lower aeration period (four hours), the synthesis is completed but no mass reduction is accomplished.

JENKINS and ORHON (1972) disagreed with the previous investigators who proposed that the contact stabilization process mechanism was a matter of storage-metabolism sequence, and postulated an alternative mechanism of

growth-death sequence. They proposed that during contact period a rapid growth of microorganisms led to an increase in activated sludge viable fraction, followed by a death phase in stabilization which decreased the viable fraction.



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### 3.5 Parameters Affecting Contact Stabilization Process

In previous time the operating and design calculation of biological wastewater treatment plant were based on empirical means.

To day two design techniques are commonly used: one technique is based on the food to microorganism ratio (ECKENFELDER, 1966) and the other on sludge age (LAWRENCE and McCARTY, 1970). The comparison of the application of these two design techniques has been presented by STENSEL and SHELL (1974).

In contact stabilization process, GUJER and JENKINS (1975 a, b) concluded that there were independent parameters; process loading, temperature, distribution of microorganisms in both tanks and recycle ratio. Therefore, the process has its design flexibility. The various recommended operating and design parameters by some investigators are summarized in Table 3.1.

### 3.6 Nutrient and Trace Element Requirements

In biological treatment system is to function properly, nutrients must be available in adequate amounts and the principal nutrients required are nitrogen and phosphorus.

METCALF & EDDY (1972) indicated that based on an average composition of cell tissue of  $C_5H_7NO_2$ , about 12.4 per cent by weight of nitrogen will be required. The amount is based on the mass of organisms produced per day. The phosphorus requirement is usually assumed to be about one-fifth of the requirement. However, these values are not fixed quantities, because it has been showed that the percentage distribution of nitrogen and phosphorus in cell tissue varies with the age of the cell and environ-

Table 3.1 - Recommended Parameters for Contact Stabilization Process  
(After SAIPHANICH, 1978)

$C_T$ or $U_T$ (day <sup>-1</sup> )	$\theta_c$ (day)	MLSS (mg/l)		Detention Time		R. %	BOD Removal %	Authers
		Contact	Stabilization	$t_c$ (hr)	$t_s$ (hr)			
-	-	3,000-4,000	4,500-6,000	0.25-0.50	1.50	100	85-99	ULLRICH et al. (1951)
-	-	1,896	6,885	0.63	5.2	41	93.4	ULLRICH et al. (1957)
0.125	7.2	2,000-3,600	10,000-20,000	2.90	10.0	-	94.3	HATFIELD (1959)
-	-	-	-	0.5-1.5	2-4	-	-	WESTON (1961)
0.283	-	1,780-5,330	4,200-10,000	1.04	4.20	41-104	89.4	HASELTINE (1961)
0.113	-	2,290	13,600-18,700	3.21	12.00	13-19	84.0	
0.166	-	2,200-3,500	8,400-11,900	2.94	18.00	46-92	87.2	
0.52-1.16	-	7,700-10,670	12,700-18,200	0.58-1.60	3.3-3.7	100-171	63-68	BOON (1969)
0.34-0.63	-	6,050-11,400	11,400-25,000	0.50-1.61	2.0-6.44	100	50-86	
0.41-0.52	-	3,500	7,100	0.30	1.67	100	91	
0.31-1.65	-	1,900-3,000	3,500-13,700	0.61	0.50	100	97	
0.20-0.60	5-15	1,000-3,000	4,000-10,000	0.5-1.0	3.0-6.0	25-100	80-90	METCALF (1972)
0.20-0.8	5-30	1,000-5,000	3,000-12,000	0.5-2.0	2.0-6.0	50-200	80-95	SAIPHANICH (1978)

\* Based on COD

mental conditions.

The other nutrients required by most biological systems are shown in Table 3.2. HELMERS et al. (1951), as reported by ECKENFELDER (1966), determined minimal quantities of nitrogen and phosphorus of 4.0 lb N/100 lb BOD removed and 0.6 lb P/100 lb BOD removed. This is approximately equivalent to a BOD:N:P ratio of 150:5:1. Their studies further indicated a minimum nitrogen content of 7 per cent and a minimum phosphorus content of 1.2 per cent of the volatile suspended solids.

Table 3.2 - Inorganic Ions Necessary for Most Organisms

(KIMBALL, 1968 as Reported by METCALF & EDDY, 1972)

Substantial Quantities	Trace Quantities
Na <sup>+</sup> (except for plants)	Fe <sup>++</sup>
K <sup>+</sup>	Cu <sup>++</sup>
Ca <sup>++</sup>	Mn <sup>++</sup>
Mg <sup>++</sup>	Zn <sup>++</sup>
PO <sub>4</sub> <sup>≡</sup>	B <sup>3+</sup> required by plants,
Cl	certain protists
SO <sub>4</sub> <sup>=</sup>	Mo <sup>+</sup> required by plants, certain
	protists, and animals
HCO <sub>3</sub> <sup>-</sup>	V <sup>++</sup> required by certain
	protists and animals
	Co <sup>++</sup> required by certain
	animals, protists, & plants
	I <sup>-</sup> } required by certain
	Se <sup>--</sup> } animals only

### 3.7 The Remedy of Sludge Rising and Sludge Bulking

Two of the major problems encountered in activated sludge process and its modification such as contact stabilization process are sludge rising and sludge bulking. These phenomena will cause of high suspended solids concentration in the effluent and decreasing the plant efficiency. Some of the possible causes and suggested remedies were reported by ECKENFELDER & FORD (1970), US. EPA 625/1-71-004a (1974) and METCALF and EDDY (1972) as following:

Table 3.3 - The Remedy of Sludge Rising and Sludge Bulking

Possible Cause	Suggested Remedy
1. Excessive organic loading	1. Reduce organic loading to system capacity or below.
2. Gasified sludge caused by denitrification of excessive anaerobic sludge holding time in clarifier.	2. Increase sludge recycle rate and/or increase sludge wastage.
3. Excessive sludge in system	3. Increase sludge wastage, expand sludge thickening and handling facilities if necessary.
4. Low DO in aeration tank or tanks	4. Normally maintain at or above 2 mg/l
5. Nature of the wastewater results in proliferation of filamentous microorganisms.	5. Maintain aeration basin contents at neutral pH; add coagulant to basin to enhance solids-liquid separation.
6. Predominance of filamentous microorganisms resulting from low N or P conc. in system.	6. Add inorganic N or P to system.

Nevertheless, if filamentous microorganisms persist in systems the suggested remedies should be concerned as following:

ECKENFELDER & FORD (1970) further suggested to chlorinate, keep sludge in anaerobic condition if possible, keep MLSS as high as possible, or purge system of sludge and re-seed.

US. EPA 625/1-71-004a (1974) suggested that chlorination had been found effective in controlling bulking due to filamentous growths. Recommended dose rates based on return sludge flow are between 0.2 and 1.0 lb of chlorine per 100 lb of return sludge solids. This method is only considered as a temporary measure and should not exceed 24 hours duration. Selective destruction of filamentous organisms by chlorination generally will come a turbid effluent until the destroyed organisms are washed out of the system. The other method was suggested to employ hydrogen peroxide at continuous dosing of 200 mg/l (based on plant influent) to the return sludge for 24 hrs. which resulted in an immediate improvement in sludge settling and a gradual recovery of system performance as reported by COLE *et al.* (1973).

WPCF-MOP No. 11 (1970) proposed to chlorinate with dosage of 10-20 mg/l on basis of return sludge volume or 0.3 to 0.6% of dry return sludge.

### 3.8 Advantages and Disadvantages of the Process

#### 3.8.1 Advantages of the Process

The advantages of the contact stabilization process cited by many investigators are summarized as following:



- (1) The contact stabilization process has ability to up-grade the conventional activated sludge plant in term of volumetric loading up to 1.5 - 3 times, ULLICH and SMITH (1951, 1957).
- (2) The process can withstand of shock loading toxic loading because of the biological buffering capacity of stabilization tank, and the fact that at any given time the majority of the biomass is isolated from the main stream of the plant flow, US. EPA 625/1-71-004a (1974), GRICH (1961).
- (3) It is possible to maintain MLSS at concentrations up to 20,000 mg/l in the stabilization tank without materially affecting the total air requirement and affecting no problem of diffuser clogging, WPCF MOP No. 11 (1970).
- (4) It is possible to reduce in the required capacity of return sludge facilities, WPCF MOP No. 8 (1959).
- (5) The contact stabilization process is applicable to the treatment of wastewaters containing a high proportion of the organic matters in suspended or colloidal form, (ECKENFELDER, 1966).
- (6) The sludge from the contact tank has markedly better settling characteristics than those of a conventional activated sludge plant, GODDARD (1974).

### 3.8.2 Disadvantages of the Process

- (1) The contact stabilization process requires skilled operator

to operate the system in effective condition than a conventional activated sludge process.

- (2) The process has greater complexity of plant piping and possibly a multiplicity of aeration devices or arrangements, WPCF MOP No. 8 (1959).



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### 3.9 Mathematical Models of Contact Stabilization Process

Mathematical models are not only necessary for a design calculation of wastewater treatment plant but also convenient to explain the correlations of various parameters used in the process.

Many investigators have proposed their biological mathematical models employing in biological wastewater treatment processes. Some of these investigators are: MICHAELIS - MENTON, MONOD (1942), HEUKELEKIAN et al. (1951), ECKENFELDER and O'CONNOR (1955), WESTON & ECKENFELDER (1955), MCKINNEY (1963), PEARSON (1966), McCARTY (1966), VAN UDEN (1967), LAWRENCE and McCARTY (1970), METCALF and EDDY (1972).

These mathematical models have been discussed and basically applied to aerobic (almost in activated sludge system) and anaerobic biological wastewater treatment systems as indicated by ECKENFELDER (1970), METCALF and EDDY (1972), GOODMAN and ENGLANDE (1974), STENSEL and SHELL (1974), JENKINS et al. (1975), KEYES and ASANO (1975).

For the design of contact stabilization process, these mathematical models have been basically proposed and applied by some investigators as following: JENKINS and ORHON (1972), GUJER and JENKINS (1975 a, 1975 b), BENEFIELD and RANDALL (1976), KHARAJAIN and SHERARD (1977, 1978), SAIPHANICH (1978), YUE (1979).

The mathematical models of carbonaceous phase which relate to the essential design parameters of contact stabilization process have been derived. The mass balance equations, the two basic mathematical models of mass production and substrate utilization rate as well as the concepts of investigators especially SAIPHANICH (1978) have been used as basic re-

ferences.

### 3.9.1 Mass Balance Equations

Fig. 3.5 showed the mass balance diagram of contact stabilization process. This mass balance diagram is indicated in terms of flow rate, substrate concentration and biomass concentration of the system. This diagram is used for the mathematical models derived in this title.

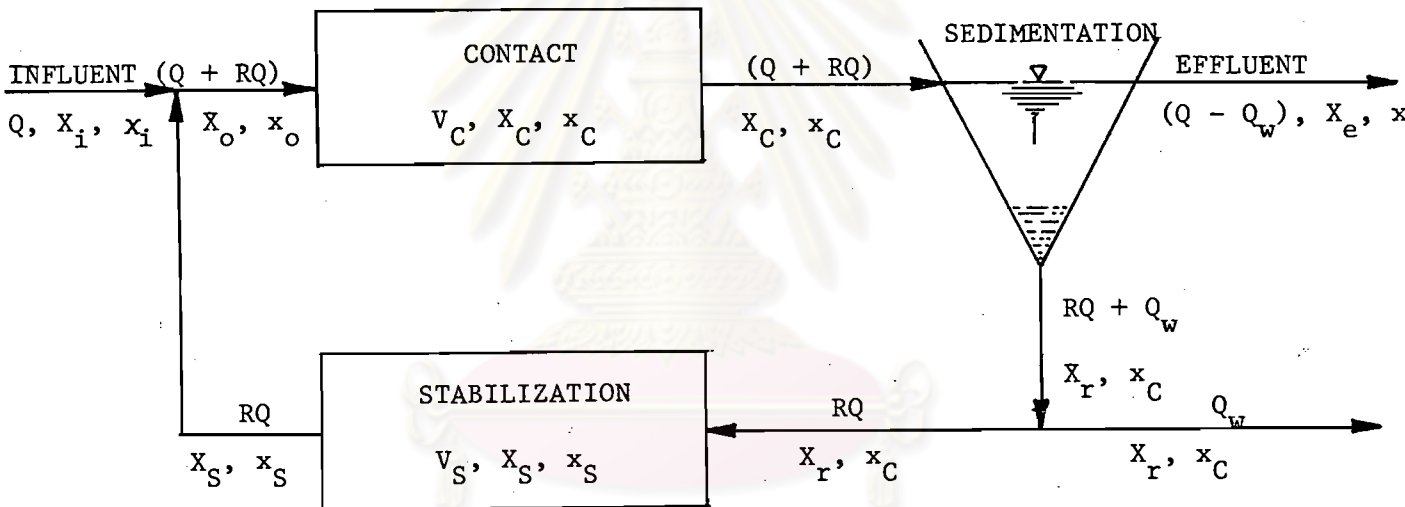


Fig. 3.5 - Mass Balance Diagram of Contact Stabilization Process

#### a) Mass Balance of Microorganisms in Contact Tank

If we define the term  $\left(\frac{dX}{dt}\right)_F$  as the net rate of change of microorganisms at definite time  $F$ . The mass balance equation in contact tank can be written as:

$$V_C \left(\frac{dX}{dt}\right)_F = RQX_S + QX_i + k_C X_C V_C - (Q + RQ)X_C \quad (3.1)$$

If we neglect the influent biomass concentration,

equation (3.1) gives:

$$\left(\frac{dX}{dt}\right)_F = \frac{RQ}{V_C} X_S + k_C X_C - (1 + R) \frac{QX_C}{V_C} \quad (3.2)$$

at steady state condition:

$$\left(\frac{dX}{dt}\right)_F = 0$$

$$k_C = \frac{(1 + R)X_C - RX_S}{X_C t_C} \quad (3.3)$$

where:  $t_C = \frac{V_C}{Q}$

$$X_C = \frac{RX_S}{(1 + R) - k_C t_C} \quad (3.4)$$

b) Mass Balance of Microorganisms in Stabilization Tank

The mass balance equation can be written as follow:

$$V_S \left(\frac{dX}{dt}\right)_F = RQX_r + k_S X_S V_S - RQX_S$$

$$\left(\frac{dX}{dt}\right)_F = \frac{RQX_r}{V_S} + k_S X_S - \frac{RQX_S}{V_S} \quad (3.5)$$

at steady state condition

$$\left(\frac{dX}{dt}\right)_F = 0$$

$$k_S = D_S \left(1 - \frac{X_r}{X_S}\right) \quad (3.6)$$

where:  $D_S = \frac{RQ}{V_S}$

$$X_S = \frac{t_r}{1 - k_S t_{SR}} \quad (3.7)$$

where: 
$$t_{SR} = \frac{V_S}{RQ}$$

c) Mass Balance of Microorganisms in Sedimentation Tank

The mass balance equation in sedimentation tank can be written as:

$$(Q + RQ)X_C = (RQ + Q_W)X_r + (Q - Q_W)X_e$$

The terms  $Q_W$  and  $X_e$  are very small, if we neglect both terms, the above equation gives:

$$X_r = \frac{(1 + R)X_C}{R} \quad (3.8)$$

d) Mass Balance of Substrate in Contact Tank

If we define the term  $\left(\frac{dx}{dt}\right)_F$  as the net rate of change of substrate at definite time F. The mass balance equation can be written as:

$$V_C \left(\frac{dx}{dt}\right)_F = Qx_i + RQx_S - (1 + R)Qx_C - \frac{k_C}{a_C} X_C V_C$$

$$\left(\frac{dx}{dt}\right)_F = \frac{Q}{V_C} x_i + \frac{RQ}{V} x_S - \frac{(1 + R)Qx_C}{V_C} - \frac{k_C X_C}{a_C} \quad (3.9)$$

at steady state condition  $\left(\frac{dx}{dt}\right)_F = 0$

$$x_C = \frac{x_i + Rx_S - k_C X_C t_C / a_C}{(1 + R)} \quad (3.10)$$

e) Mass Balance of Substrate in Stabilization Tank

The mass balance equation can be written as follow:

$$V_S \left( \frac{dx}{dt} \right)_F = RQx_C - RQx_S - \frac{k_S}{a_S} X_S V_S$$

$$\left( \frac{dx}{dt} \right)_F = D_S x_C - D_S x_S - \frac{k_S}{a_S} X_S; D_S = \frac{QR}{V_S} \quad (3.11)$$

at steady state condition

$$\left( \frac{dx}{dt} \right)_F = 0$$

$$x_S = x_C - \frac{k_S X_S t_{SR}}{a_S}, t_{SR} = \frac{V_S}{RQ} \quad (3.12)$$

substitute  $x_S$  of equation (3.12) to equation (3.10)

$$x_C = x_i - \frac{k_C}{a_C} X_C t_C - \frac{k_S}{a_S} X_S t_S \quad (3.13)$$

$$\text{where: } t_C = \frac{V_C}{Q}; t_S = \frac{V_S}{Q}$$

from equation (3.13), effluent substrate concentration is generally formed as:

$$x_C = x_i - t_C \left( \frac{dx}{dt} \right)_C - t_S \left( \frac{dx}{dt} \right)_S \quad (3.14)$$

### 3.9.2 Mathematical Models

The two mathematical models of biomass production and substrate removal rate as indicated in equation (3.15) and (3.18) have used as the basic equations for the mathematical models of contact stabilization process. The first mathematical model was originally developed by HEUKELIKIAN et al. (1951) and second mathematical model by HERBERT (1958). These two mathematical models were

modified by LAWRENCE and McCARTY (1970), METCALF and EDDY (1972), SAIPHANICH (1978).

The biomass production mathematical model is:

$$\frac{dX}{dt} = a \frac{dx}{dt} - k_2 X \quad (3.15)$$

$$\text{divide by } X: k = \frac{1}{\theta_C} = \frac{1}{X} \cdot \frac{dX}{dt} = \frac{a \, dx/dt}{X} - k_2 \quad (3.16)$$

$$\text{or: } \frac{1}{\theta_C} = aU - k_2 \quad (3.17)$$

where:  $k$  = net specific growth rate of microorganisms ( $T^{-1}$ )

$$\theta_C = \text{sludge age} \quad (T)$$

$$= \frac{\text{Total mass of microorganisms in the system}}{\text{mass of microorganisms wastes per day}}$$

$$= \frac{X}{dX/dt}$$

$$U = \text{specific substrate utilization rate} (T^{-1})$$

$$= \frac{\text{Substrate utilization rate}}{\text{mass of microorganisms in the system}}$$

$$= \frac{dx/dt}{X}$$

$$a = \text{growth yield coefficient} \quad (\text{NON})$$

$$k_2 = \text{microorganisms decay coefficient} (T^{-1})$$

The substrate removal rate mathematical model is:

$$\frac{dx}{dt} = \frac{K_O \, xX}{K_S + x} \quad (3.18)$$

divide by  $X$ :



$$U = \frac{1}{X} \frac{dx}{dt} = \frac{K_o x}{K_S + x} \quad (3.19)$$

where:  $K_o$  = maximum rate of substrate utilization ( $T^{-1}$ )

$K_S$  = half velocity coefficient ( $ML^{-3}$ )

= substrate concentration when  $U = 1/2 K_o$

$$\text{From: } U = \frac{Q(x_i - x_e)}{M} \quad (3.20)$$

rewrite equation (3.19) and (3.20) as:

$$\frac{Q(x_i - x_e)}{M} = K_o \frac{x_e}{K_S + x_e} \cdot \frac{Q/M}{Q/M}$$

$$U = \frac{K_o Q x_e / M}{(K_S + x_e) Q / M} \quad (3.21)$$

$$\text{Efficiency of system } \eta = \frac{x_i - x_e}{x_i} \quad (3.22)$$

$$x_e = (1 - \eta)x_i$$

$$Q \frac{x_e}{M} = (1 - \eta) \frac{Qx_i}{M} \quad (3.23)$$

substitute equation (3.23) into equation (3.21)

$$U = \frac{K_o \frac{Qx_i}{M}}{\frac{K_S Q}{(1 - \eta)M} + \frac{Qx_i}{M}}$$

or:

$$U = \frac{K_o \cdot C}{\gamma + C} \quad (3.24)$$

where:  $C = \text{organic loading} = \frac{Qx_i}{M}$  (3.25)

$$Y = \frac{K_S Q}{(1 - \eta)M} \quad (3.26)$$

Total biomass in the system ( $M_T$ ) define as:

$$M_T = V_C X_C + V_S X_S + V_{ST} X_{ST} \quad (3.27)$$

$$= M_C + M_S + M_{ST}$$

$$\alpha = \frac{V_C X_C}{M_T} = \frac{M_C}{M_T} \quad (3.28)$$

$$\beta = \frac{V_S X_S}{M_T} = \frac{M_S}{M_T} \quad (3.29)$$

$$\phi = \frac{V_{ST} X_{ST}}{M_T} = \frac{M_{ST}}{M_T} \quad (3.30)$$

$$\alpha + \beta + \phi = \frac{V_C X_C + V_S X_S + V_{ST} X_{ST}}{M_T} = 1 \quad (3.31)$$

when  $\phi$  is negligible compare to  $\alpha$  and  $\beta$ , the equation (3.31)

gives:

$$\alpha + \beta = 1 \quad (3.32)$$

The detention time in contact and stabilization tank are as

following:

$$t_C = \frac{V_C}{Q} \quad (3.33)$$

$$t_{CR} = \frac{V_C}{(1 + R)Q} \quad (3.34)$$

$$t_S = \frac{V_S}{Q} \quad (3.35)$$

$$t_{SR} = \frac{V_S}{RQ} \quad (3.36)$$

based on total system, from equation (3.17) and (3.20) give:

$$\frac{1}{\theta_C} = \frac{a Q (x_i - x_e)}{M_T} - k_2$$

$$M_T = \frac{a Q \theta_C (x_i - x_e)}{1 + k_2 \theta_C} \quad (3.37)$$

if suppose no degradation in sedimentation tank equation (3.37)

gives:

$$M_T = \frac{a Q \theta_C (x_i - x_e)}{1 + k_2 \theta_C} \quad (3.38)$$

from equation (3.20), (3.22) and (3.25) give:

$$U_T = \eta_T C_T \quad (3.39)$$

based on contact tank, it could be written as:

$$U_C = \eta_C C_C \quad (3.40)$$

where:

$$U_C = \frac{Q \{x_i + R x_S - (1 + R) x_C\}}{M_C} \quad (3.41)$$

$$C_C = \frac{Q (x_i + R x_S)}{M_C} \quad (3.42)$$

$$\eta_C = 1 - \frac{(1 + R) x_C}{x_i + R x_S} \quad (3.43)$$

based on total system and contact tank, equation (3.24) obtained:

$$U_T = \frac{(K_O)_T \cdot C_T}{\gamma_T + C_T} \quad (3.44)$$

and 
$$U_C = \frac{(K_O)_C \cdot C_C}{\gamma_C + C_C} \quad (3.45)$$

From equation (3.39) and (3.44), (3.40) and (3.45) give:

$$\eta_T = \frac{(K_O)_T}{\gamma_T + C_T} \quad (3.46)$$

$$\eta_C = \frac{(K_O)_C}{\gamma_C + C_C} \quad (3.47)$$

From equation (3.44)

$$U_T = \frac{(K_O)_T \cdot C_T}{\gamma_T + C_T} \cdot \frac{x_e / C_T}{x_e / C_T}$$

$$\frac{(K_O)_T \cdot x_e}{\gamma_T \cdot \frac{x_e}{C_T} + x_e}$$

Compare with equation (3.19), it could be written as:

$$(K_S)_T = \gamma_T \cdot \frac{1}{C_T} \cdot x_e \quad (3.48)$$

by same method:

$$(K_S)_C = \gamma_C \cdot \frac{1}{C_C} \cdot x_c \quad (3.49)$$

$$\frac{(K_S)_C}{(K_S)_T} = \frac{\gamma_C C_T \cdot x_C}{\gamma_T C_C \cdot x_e}$$

If non degradation in sedimentation tank,  $x_C = x_e$  so:

$$\frac{(K_S)_C}{(K_S)_T} = \frac{\gamma_C \cdot C_T}{\gamma_T \cdot C_C} \quad (3.50)$$

From equation (3.26), it could be written as:

$$(K_S)_T = \frac{\gamma_T(1 - \eta_T)M_T}{Q} \quad (3.51)$$

$$(K_S)_C = \frac{\gamma_C(1 - \eta_C)M_C}{(1 + R)Q} \quad (3.52)$$

$$\frac{(K_S)_C}{(K_S)_T} = \frac{\gamma_C(1 - \eta_C)}{\gamma_T(1 - \eta_T)} \cdot \frac{M_C}{M_T} \cdot \frac{1}{(1 + R)} \quad (3.53)$$

Compare equation (3.50) and (3.53):

$$\frac{\gamma_C}{\gamma_T} \cdot \frac{C_T}{C_C} = \frac{\gamma_C}{\gamma_T} \cdot \frac{(1 - \eta_C)}{(1 - \eta_T)} \cdot \frac{\alpha}{1 + R}$$

rearrange:  $\eta_C = 1 - \frac{C_T(1 - \eta_T)(1 + R)}{C_C \cdot \alpha}$  (3.54)

Substitute Eq. (3.19) into equation (3.17) and based on the total system:

$$x_e = \frac{(K_S)_T(1 + k_2\theta_C)}{\theta_C \{a(K_O)_T - k_2\} - 1} \quad (3.55)$$

Substitute Eq. (3.48) into equation (3.55):

$$C_{TT} = \frac{\gamma_T(1 + k_2\theta_C)}{\theta_C \{a(K_O)_T - k_2\} - 1} \quad (3.56)$$