A hybrid reactor consists of both suspended and attached (biofilm) growth in a single reactor. As such, the level of its total biomass can be maintained at much higher than 3000 mg/L without encountering subsequent sludge settling problem. This will significantly increase the treatment capacity of a biological system. Besides, the sludge age of the attached growth is much longer than that of the suspended growth. This will allow nitrifiers to be maintained in the biofilm even if the suspended growth is operated at 1 to 2-day short sludge age. The biomass of shorter sludge age (1 to 2 days) has a much higher bioactivity as compared to that of an older sludge age (as in conventional activated sludge system). Thus, a hybrid reactor can significantly increase the treatment capacity.

Based on the above context, a systematic study was conducted using a 14-L cylindrical (200 mm dia.) hybrid reactor to assess the relative bioactivities and the overall contributions of both suspended and attached growth with respect to carbonaceous removal and nitrification under different SRT and operating DO. The SRT of the suspended growth was varied from 0.17d to 6.5 d while the operating DO was maintained at two levels: 3-4 mg/L and 5-6 mg/L. A synthetic substrate containing glucose and peptone was used as the influent feed with an organic loading of 4.2 kg COD/m³·d and a nitrogen loading of 0.78 kg TKN/m³·d. The bio-carrier consisted of shredded tyre beads, about 1-2 mm in size, which was added to the reactor at 20 g/L. This provided a specific growth surface of 74 m²/m³. The operating temperature was controlled at 25°C while the pH at 7.2-7.5.

The unit bio-activity was quantified by measuring either the specific TOC removal rate or the specific nitrification rate for both suspended and attached growth, separately, in batch determinations after the reactor reached steady state operation. The effects of the sludge age (with respect to suspended growth) on the bio-activity were shown in Fig. 1 and 2.
Fig. 1 clearly illustrates that the unit carbonaceous bioactivities for both suspended and attached biomass decreased with increasing SRT. This was particularly true for the suspended growth, which had an activity of 1,950 mg TOC/g-biomass-d at 0.17-d SRT but decreased to only 380 mg TOC/g-biomass-d at 6.5-d SRT. Thus, even the total suspended biomass level in the reactor was reduced at a shorter SRT, the overall carbonaceous activity was not sacrificed because of the much higher unit bioactivity. The carbonaceous activity for the attached growth was much lower than the suspended growth because the biofilm had a much higher sludge age and also a higher fraction of nitrifiers. At 0.74-d SRT, the attached growth’s carbonaceous activity was approximately 400 mg TOC/g-biomass-d, which was similar to that observed for the suspended growth at 6.5-d SRT. Thus, it is reasonable to say that the sludge age of the attached growth was approximately 6 days.

As expected, the specific nitrification activity increased with increasing SRT for both suspended and attached growth (Fig. 2). Of significance is the fact that even at 0.17-d SRT, the attached growth still had a high specific activity of 155 mg TKN/g-biomass-d while the suspended had only 35 mg TKN/g-biomass-d. Obviously, the presence of any nitrifier in suspended growth under such a short SRT must come from biofilm sloughing. This points out a distinct advantage of hybrid reactor in its capability of continuously supplying nitrifiers to its suspended growth regardless of the short sludge age operation. As the SRT was increased to 0.74-d, the specific nitrification activities were increased to 200 and 125 mg TKN/g-biomass-d, respectively, for the attached and the suspended growth. These high levels of nitrifier activity are not often seen in a purely suspended growth system, particularly at such a short sludge age (0.74-d).

The relative biomass distributions in a hybrid reactor were highly affected by the operating SRT. It was found that as the SRT was changed from 0.17 d to 6.5 d, the level of suspended biomass increased from 338 to 6,349 mg/L while attached biomass decreased from 1,247 to 210 mg/L. This clearly indicated that the hybrid system shifted from biofilm predominant to suspended-growth
predominant. The overall contribution ratio of the two types of growth toward organic and ammonia removal could be calculated by multiplying the “ratio of their specific substrate removal rates” by the “ratio of their biomass concentrations”. With the contribution ratio, it becomes possible to estimate the relative contributions between the two growth types toward the overall carbonaceous removal and nitrification at any given SRT, as shown in Figs. 3 and 4. Two salient points are reflected in Fig. 3. First, regardless of the operating SRT, the overall TOC removal rate remained relatively constant, reflecting that the maximum TOC removal rate was limited by the available substrate, not carbonaceous bioactivity. Second, the removal loading shifted drastically from the attached to the suspended growth when the SRT was increased.

Fig. 4 shows that the volumetric nitrification rate of the suspended growth and its contribution to the total nitrification increased phenomenally with increasing SRT. In estimating the nitrification rate, the portion of ammonia utilized by cellular synthesis was calculated from the observed sludge production rate and this fraction was subtracted from the nitrification rate. The overall nitrification rate reached a maximum level of 0.66 kg N/m³-d at 3.0-d SRT, and in this case most nitrification was accomplished by the suspended growth. When the SRT was reduced to 0.17 d, the rate was reduced to only 0.085 kg/m³-d, and 95% of this was contributed by the attached growth. At 0.74-d SRT, the rate was increased to 0.40 kg/m³-d, and 73% of that was contributed by the attached growth.

The nitrification performance of a hybrid reactor was also highly dependent on the operating DO. When DO was increased from 3-4 mg/L to 5-6 mg/L, the nitrification rate also increased immediately.
from about 0.1 kg N/m$^3$-d to approximately 0.22 kg N/m$^3$-d. After about 6-week operation, the operating DO was returned back to 3-4 mg/L for two weeks. It was found that the nitrification rate quickly declined to 0.15 kg N/m$^3$-d, as shown in Fig. 5. The reason that the nitrification rate did not retreat back to the original 0.1 kg N/m$^3$-d was because the nitrifying populations in biofilm had increased during the high-DO operation at 5-6mg/L. This was also evident that the average attached biomass level increased from 1,247 mg/L in the first stage (DO=3-4mg/L) to approximately 2,000 mg/L at the end of the second stage (DO=5-6 mg/L) operation.

![Fig. 5. Effect of DO on Nitrification Rate at SRT of 0.17d](image)

**CONCLUSIONS**

Based on the findings of this study, the following conclusions can be drawn:

1. A hybrid reactor can substantially increase the system's nitrification capacity as compared to a purely suspended growth reactor. This is particularly true for short SRT (less than 2 days) operation.

2. For a hybrid reactor receiving 4.2 kg COD/m$^3$-d and 0.78 kg TKN/m$^3$-d loading, it can achieve an organic removal rate of 3.9-4.0 kg COD/m$^3$-d at SRT varying from 0.17d to 6.5d. Its nitrification capacity depends on the SRT of the suspended growth. At 0.74-d and 3.0-d SRT, the rates are 0.4 and 0.63 kg N/m$^3$-d, respectively.
3. The biomass distributions and their relative contributions toward COD removal and nitrification in a hybrid reactor depend on the SRT of the suspended growth. At 0.17-d SRT, attached growth accounts 78% of the total biomass in the reactor, but this is reduced to 3% when the SRT is increased to 6.5 d SRT.

4. To realize the maximum benefit of using a hybrid reactor, the optimum SRT of the suspended growth lies between 1 and 2 days. When the SRT is 3 day or longer, the total biomass in the reactor is mainly composed of the suspended growth, and thus the reactor behaves much like a purely suspended growth system.

5. The nitrification capacity of a hybrid reactor can be greatly increased by increasing the operating DO. To maximize nitrification, it is better to keep the operating DO at above 5 mg/L.