produces biogas 3909ton per year. The biogas upgrading process produces waste gas at a rate of 327kg/h. The results are shown in Table 3. It can be seen that the higher CH_4 concentration results in higher released heat from reaction. When the CH_4 content is 0.65%, there is no need for supplemental energy. More supplemental energy is needed for the treatment of lower CH_4 concentration waste gas, which are 6.92MWh/year and 30.45MWh/year when the CH_4 contents are 0.42% and 0.28%, respectively. The corresponding consumption of natural gas are 743m^3/year and 3273m^3/year, respectively when natural gas is used as the supplemental fuel. It was found that the supplemental energy per unit CH_4 removal increases with the decrease of CH_4 content. When the CH_4 contents are 0.42%, 0.41% and 0.28%, the energy consumptions are 1.22kWh/kg, 1.41kWh/kg and 8.05kWh/kg, respectively.

Tab. 3 Simulated results of RTO for different cases

Biogas upgrading plant	Water scrubbing			
CH_4%	0.42	0.41	0.65	0.28
Technical performance				
Released heat from reaction (kW)	9.839	9.704	14.733	6.571
Supplemental energy (MWh/year)	6.92	7.89	0	30.45
Natural gas consumption (m^3/year)	743	848	0	3273
Supplemental energy per unit CH_4 removal (kWh/kg)	1.22	1.41	0	8.05
Environmental performance				
N_2O emission (ppm)	0.0023	0.0024	0.0019	0.0023
NO_2 emission (ppm)	0.4153	0.4221	0.3419	0.4189
NO emission (ppm)	360.248	365.875	319.918	362.801
CH_4 elimination (ton/year)	5.67	5.59	8.49	3.79
Extra CO_2 production (ton/year)	15.55	15.33	23.29	10.38
N_2O emission (ton/year)	8.63E-06	8.99E-06	7.11E-07	8.76E-06
CO_2 equivalent avoidance (ton/year)	154.53	152.41	231.38	103.19

NO_x can be formed in RTO, including NO, N_2O and NO_2. Although the content of NO_2 and N_2O are low, NO removal technology should be employed since high content of NO can be transferred to NO_2, which will cause secondary pollution. Although the negative effect of both N_2O formation and extra CO_2 production are considered, RTO also results in positive CO_2 equivalent avoidance. The CO_2 equivalent avoidance is found to increase when the CH_4 concentration increases, which are 231.38ton/year and 103.19 ton/year when the CH_4 contents are 0.65% and 0.28%.

4. DISCUSSION AND CONCLUSIONS

4.1 Discussion

Since methane-air reaction is simplified to one-step mechanism, it cannot reflect the actual complicated reaction, such as intermediate products and free radicals. It is expected that the performance of the models can be improved by employing two-step methane-air reaction mechanism or even more complicated reaction package (such as chemkin-gri30) [4].

4.2 Conclusions

A three-dimensional numerical model is used to investigate the technical and environment performance to remove CH_4 from waste gas of the biogas upgrading plant by using RTO. Based on the results, the following conclusions were drawn:

- The operation of RTO can be self-maintained in the case of 0.65% CH_4 content.
- Supplemental energy is needed to maintain CH_4 removal, in the other three cases with 0.42%, 0.41%, and 0.28% CH_4 content.
- Demand of supplemental energy decreases with the increase of CH_4 content. It will decrease from 8.05kWh/kg to 1.22kWh/kg when CH_4% rises from 0.28% to 0.42%.
- CO_2 equivalent avoidance increases with the increase of CH_4 content. For a case study with 3909ton/year of biogas production, CO_2 equivalent avoidance is 231.38ton/year.

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