Marine oily wastewater treatment: process simulation and control using soft computing approaches

The chronic discharge of oily wastewater, mainly including bilge water, offshore produced water and ballast water, has been referred to as a major contributor to marine oil pollution. Although gravity - based treatment techniques (e.g., hydrocyclone and gravity separator) have been widely used to separate oil from wastewater, many dissolved toxic/carcinogenic organics, particularly Polycyclic Aromatic Hydrocarbons (PAHs), are not likely to be effectively removed and may cause severe environmental problems. Further treatment has therefore become necessary for the shipping and offshore oil and gas industries, particularly in the harsh environments (e.g., the Arctic Ocean) where ecosystems are extremely vulnerable. Among many chemical and biological treatment techniques, ultraviolet (UV) irradiation and advanced oxidation techniques have been recently regarded as promising solutions to the removal of PAHs.

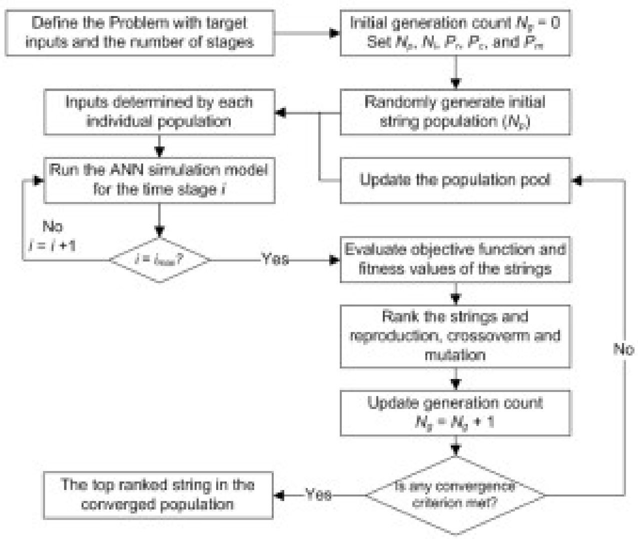

Fig.1. Flowchart of the SDMINP approach

Many studies have experimentally investigated the degradation of PAHs in fresh water systems by using UV irradiation or its combination with other oxidants. However, it is still unclear how efficient these techniques are in removing PAHs from marine oily wastewater and how changing operational conditions (e.g., salinity, chemical dose and temperature) can influence the efficiency. This may hinder their widespread applications in shipping and offshore oil and gas industries.
In response to such gaps, this study presented a simulation-based dynamic mixed integer nonlinear programming (SDMINP) process control approach by integrating process simulation, dynamic process control and systems optimization based on experimental investigation. The core idea was to change the controllable factors regularly in order to meet the varying needs regarding

process efficiency and cost. The UV-induced photodegradation of naphthalene in oily seawater was used as a demonstrative example. Based on the experimental results, a three-layer feed-forward artificial neural network simulation model was first successfully developed to predict the removal performance with good overall agreement. The SDMINP approach was then developed by integrating the simulation model, genetic algorithm and multi-stage programming (Fig. 1.).

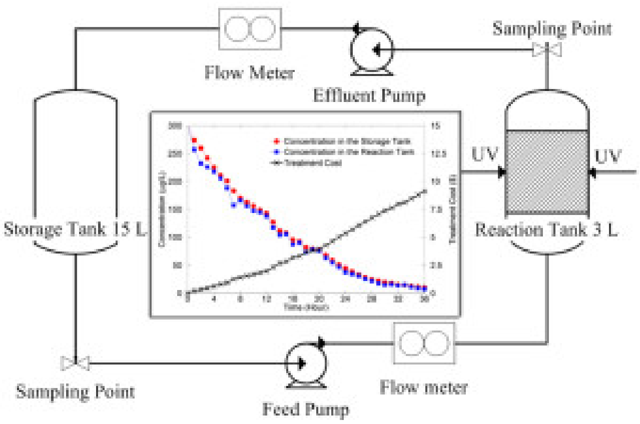

Fig.2. Naphthalene concentrations in the storage and reaction tanks and cumulative treatment cost during the 36-h treatment period

A case study targeting the removal of naphthalene through a continuous flow system in 36 hours was carried out as shown in Fig. 2. The total volume of naphthalene polluted seawater was 15 L and the controllable parameters, including the number of UV lamps and the pumping rate, could be changed on an hourly basis. The results showed that the SDMINP approach, with the aid of the dynamic multi-stage control strategy, was able to significantly reduce treatment ($9.11) cost when comparing to the traditional single-stage ($11.45, fixed operational parameters) process optimization. A Monte Carlo simulation was also performed to conclude that if the operator randomly set the flow rate and the number of lamps as constants during the 36-hour period, then there would be a great chance that the treatment standard cannot be met. If considering time as another changeable variable, then the treatment cost reached its minimum at 27 hours with $8.71 and $8.94 for the SDMINP approach and the single-stage optimization, respectively. A sensitivity analysis for the number of stages demonstrated that, regardless the length of treatment period, more optimization stages can generally reduce treatment cost, but may lead to extra manpower needs and affect system stability. It was recommended to first seek the best solution with less optimization stages, and then using the solution as an initial population for more optimization stages, if necessary. Such an experimentation, data analysis, process simulation, and process control framework can be easily modified and applied to other research fields where experimental and numerical approaches are used in a complementary way.

Publication

Process simulation and dynamic control for marine oily wastewater treatment using UV irradiation.
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