

lilies⁴. This location supports the idea that the basal plates and a sufficiently long part of the stalk are crucial to regeneration of the entire crown in sea lilies. The function of the stalk in sea lilies is to elevate the crown above the substrate⁵. Our results indicate that the nutrients and materials from the stalk, especially from the upper 5 cm, are used for crown regeneration.

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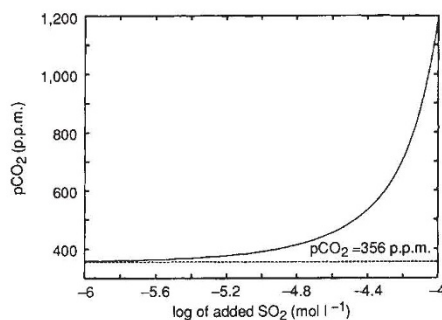
Disposal of SO₂ in sea water

SIR — Radojević and Tressider¹ confirm that gaseous SO₂ easily dissolves in sea water². They propose that seawater scrubbing may be used to reduce the anthropogenic emissions of SO₂, and that SO₂ could be injected "directly into an ocean current with no perceptible effect on seawater pH or composition". We find this statement misleading — in practical applications the injected SO₂ could lead to outgassing of oceanic CO₂, and thus contribute to further increase in the greenhouse effect.

The acidification of sea water as the injected SO₂ oxidizes to sulphate results in a shift in the inorganic carbon system; the carbonate and bicarbonate concentrations decrease whereas the concentration of dissolved CO₂ increases. The partial pressure of CO₂ as a function of only minor amounts of added sulphur dioxide is shown in the figure. The partial pressure of CO₂ (pCO₂) is 3 p.p.m. above its equilibrium value for an excess sulphate concentration of 10⁻⁶ mol l⁻¹, and a doubling of the equilibrium pCO₂ value occurs for 6.3 × 10⁻⁵ mol of added SO₂ l⁻¹.

If water with excess sulphate concentration greater than 10⁻⁶ mol l⁻¹ is in contact with the atmosphere, rapid outgassing of CO₂ would occur due to the increased pCO₂. To keep the concentration of the added sulphur below 10⁻⁶ mol l⁻¹, the 4 × 10³ g SO₂ s⁻¹ emitted from a 2-GW power plant¹ would have to be dissolved in a water volume of at least 6 × 10⁴ m³ every second. Most ocean currents are characterized by flow velocities well below 1 m s⁻¹, so this option requires an enormous diffuser device in order to dilute the injected SO₂.

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Partial pressure of CO₂ in sea water as a function of added SO₂. The ambient sea water has a temperature of 10°C and salinity of 35 PSU, the total dissolved inorganic carbon content is 2.12 × 10⁻³ mol l⁻¹, and the alkalinity is 2.35 × 10⁻³ eq l⁻¹. This gives an equilibrium pCO₂ value of 356 p.p.m. The boric acid system has been included in the computations.

er device in order to dilute the injected SO₂.

For SO₂ disposal to be a practical option, currents leading from shallow water into the deep ocean are required. There are only a few natural sinking ocean currents, an example being the Mediterranean overflow into the Atlantic. However, negatively buoyant plumes may be created by dissolving CO₂ in sea water at elevated pressures^{3,4}, and thereby transport the water to the deep ocean. There might be a possibility for using a similar scheme for SO₂ or a combination of CO₂, SO₂ and other gases which dissolve in sea water, provided the gases have the property that they increase the density of the discharged water.

While disposal of flue gases into the ocean may have a potential to reduce atmospheric emissions, careful studies of the biological and environmental consequences of each gas are required before disposal can be implemented.

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SIR — Although the suggestion of Radojević and Tressider¹, that combustion emissions be piped below the sea to absorb SO_x and NO_x, may be attractive chemically, it does not hold water energetically. The engineers who design exhaust and cleaning systems for flue gases have to pay serious attention to the energy costs. Industrial electrostatic precipitators and bag filters currently in use for removing particles might involve a pressure drop of 1.47 kPa (150-mm water gauge).

Assume that the outfall of such a system has got to be far enough off shore

to give it a depth below the surface of, say, 10 m. A 2,000-MW electricity generating station would have a total gas emission rate of 2,000 m³ s⁻¹. Hence the power used to overcome the pressure drop due to the depth of water would be dV/dt × dP, or 2,000 × (10 × 1,000 × 9.81), around 200 MW. The station would thus use 10% of its own power output to clean its own flue gases. Add to this waste the probability that less than 100% of the gases would be absorbed, the thermal input from flue gases at 120°C and the creation of foaming toxic regions of sea with consequent damage to marine flora and fauna — surely this could never be the best environmental option.

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RADOJEVIĆ REPLIES — Drange and Haugan, and Colls, raise some important issues following from our report¹. Whether our proposal is economically viable depends on the value one attaches to the environment and its protection as well as any energy "penalty". Currently popular limestone-based desulphurization techniques involve enormous expense, for example.

We did not discuss desorption of CO₂ from acidified solutions, although this is a possibility. We have carried out some preliminary experiments in which CO₂ (13% in air) was bubbled into sea water. The sea water has some CO₂-absorbing capacity although this was lower than that for SO₂. Absorption of CO₂ is a reversible process, unlike absorption of SO₂ which is rapidly oxidized to sulphate, a stable product. In real applications of the proposed desulphurization method the extent of CO₂ desorption will depend on dilution factors, depth of discharge and other parameters, and will be limited to the locality of discharge. Once the effluent is diluted to background levels desorption of CO₂ will become unimportant.

Methods involving direct discharge of flue gases into sea water are still in the development stage and until actual field trials are carried out some of the questions raised above will remain unanswered. At first it may be more practical to apply the technique to smaller industrial plants until some of the technical problems are resolved. The case of the 2,000-MW plant in our report was used only as an illustration and we are still some way off from applying the method to such large plants.

Sea water is a far more suitable recipient for combustion-generated pollution