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Nanotubes go with the flow

Bangalore Scientists in Bangalore have succeeded in generating electricity on a tiny scale by running water over carbon nanotubes. This finding may one day be used in a new type of power plant — but it is already showing potential for use in sensitive flow sensors with a range of biomedical applications.

Ajay Sood of the Indian Institute of Science and his student Shankar Ghosh, working with N. Kumar of the Raman Research Institute (Figure 1), have demonstrated this potential by a simple experiment. They packed a bundle of single-walled carbon nanotubes (SWNTs) between two metal electrodes and placed it in the centre of a glass cylinder filled with different liquids. Making the fluids flow over the bundle produces a voltage, the magnitude of which increases with the flow speed.

The researchers reported in *Science*[1] that the flow of a liquid over SWNT bundles induces a voltage along the direction of the flow (along the width) rather than perpendicular to it. What surprised the team was the sensitivity of the device: it generates a voltage of 0.65 mV even when the flow speed was as low as 5 micrometres (thousandths of a millimetre) per second.

The SWNT bundles, which had an average tube diameter of 1.5 nanometres (millionths of a millimetre), were prepared in C. N. R. Rao's laboratory in Bangalore by the electric-arc method followed by purification. The device itself is about a millimetre long.

The scientists found that the rise in voltage follows a logarithmic scale, and is dependent on the ionic conductivity of the liquid. For instance, the voltage generated by dilute hydrochloric acid is about five times greater than that produced by flowing water at the same velocity. The trio also found that polar liquids such as water produce a bigger voltage than less polar liquids, like methanol. The voltage is also greater for less viscous fluids.

Sood told *NewsIndia* that the researchers have not shown that the liquids actually flow through the carbon nanotubes: "We think that it will be flowing outside as well as inside the tube. But we have not proved it experimentally."

The one-dimensional nature of the SWNT — electrons are only free to move along their length — is crucial for the

Figure 1 The generation game: from left, N. Kumar, Ajay Sood and Shankar Ghosh have obtained voltage by flowing fluids of water over carbon nanotubes.

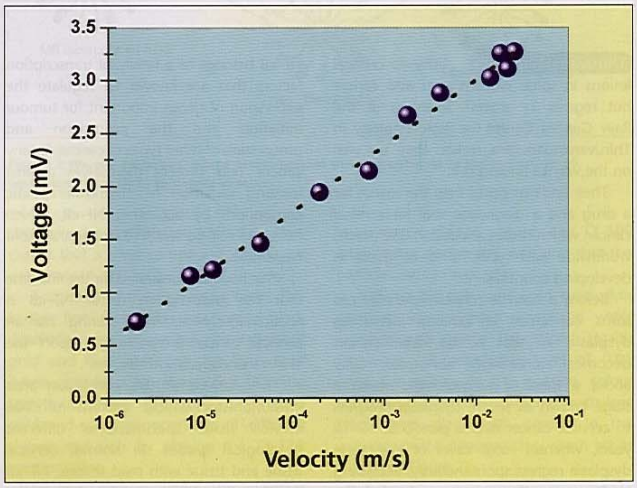

Figure 2 Current work: the voltage developed across the nanotube sensor increases with liquid flow velocity. The straight dotted line shows a logarithmic rise.

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generation of an electrical signal in the sample, the scientists say. For instance, experiments on graphite did not produce any measurable electrical signal, and multi-walled carbon nanotubes did generate a voltage but it was about 10 times smaller than that produced by the SWNT.

According to the authors, the most striking feature of their experimental data is the slow, almost saturating growth of the induced voltage with increasing flow velocity. They explain that the strongly sublinear, almost logarithmic dependence on the flow velocity (Figure 2) should involve a direct interaction between the electrons in the nanotubes and the fluctuating electric field as the ions in the liquid flow past.

Sood believes that the device could be used as a flow sensor. Scaling it down to just a few micrometres in length could allow it to work in very small volumes of liquid. "This sensor is unique because it can sense very low fluid velocities, as small as one micrometre per second," he says. "The high sensitivity at low velocities and a fast response time (better than 1 ms) could lead to applications in control electronics."

The device could also be used to convert mechanical energy from flowing fluids into voltage, says Sood. Such a device could have biomedical applications," he adds. For example, the Bangalore team is looking at the possibility of using the carbon bundles inside blood vessels to power coronary pacemakers, thereby eliminating the need for batteries. Sood has already applied for both US and Indian patents.

1. Ghosh, S., Sood, A. K. & Kumar, N. *Science* **299,** 1042–1044 (2003).

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