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Chemical Engineering Home-Practicals: Towards Making Distance Education Truly Distant*

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This paper describes how some important experiments, which typically rely on expensive equipment and large quantities of chemicals that are a load on the environment, may be redesigned for safe demonstration at home. Practicals from Reaction Engineering and Pollution Control Equipment, two final-year chemical engineering courses at Peradeniya's Engineering Faculty, Sri Lanka, are given as examples. The paper also describes how a digital camera and CDs may be used in conjunction with Web pages to guide students in performing these at-home experiments and how certain practicals may also be given as computer simulations to be done away from the educational centre.

INTRODUCTION

DISTANCE EDUCATION provides a means of democratizing educational opportunities for working persons, women and housewives, and the poor. In Sri Lanka, the University Grants Commission (UGC) has in the recent past underscored the importance of distance delivery of education even for conventional universities and now stresses 'dual modes of delivery' in all universities, as is the case with many universities worldwide. Therefore, in equal measure to specialists in the open and distance education, educators in conventional programmes are called upon to be ready for dual delivery.

In fact there is a further national imperative in Sri Lanka. According to World Bank predictions, unless at least 8% of the university-age population (aged 18–22) is engaged in university education, there is little chance of reaching Newly Industrialised Country status. While the present figure for university attendance is 40% in the US and 11 % in Malaysia, it is a mere 2.3% in Sri Lanka. Therefore, the economic advancement of the country hinges on getting significantly more students into the university-going category. To reach those many with no opportunity in conventional education, we must rely on distance education. The question then becomes: how do we make distance education succeed?

To date, engineering and science distance-education courses that involve laboratory work have not been truly distant [1]. In fact, students are required to perform laboratory work at a central complex for as much as one month per year of study. This requirement imposes a great difficulty on those for whom distance education is primarily intended, working persons and housewives. Indeed, in engineering, dropout rates in distance education have been high and the burden of taking extended leave from work is one of the chief reasons. The need for student-teacher conferences and assessment also usually necessitates attendance at a central complex and is another problem in the implementation of distance education.

As educators we therefore look for means of making distance education truly distant. This goal can only be achieved in degrees. The first author, along with co-workers, has addressed the problem of student-teacher interaction through Web-based teaching [2] and of assessment through on-line examinations [3]. These innovations make it unnecessary for students to come to a central complex to meet their teachers for discussions and quizzes. This paper describes learning/teaching micro-models in chemical engineering and industrial chemistry that allow preliminary laboratory work to be completed at the home. This approach not only shortens the required stay at the central complex but also enhances student learning. While not all lab work can be done at home, the intention is to make as much of it as possible to be done there and to enhance the practical component of distant-education courses. An added advantage is the use of micro-scale experiments, a feature of green-teaching methodology [4] aimed at waste minimisation.

This paper describes how some important experiments, which typically rely on expensive equipment and large quantities of chemicals that are a load on the environment, may be redesigned for safe demonstration at home. Practicals from Reaction Engineering [5] and Pollution Control

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Equipment, two final-year chemical engineering courses at Peradeniya's Engineering Faculty are given as examples. The paper also describes how a digital camera and CDs may be used in conjunction with Web pages to guide students in performing these at-home experiments and how certain practicals may also be given as computer simulations to be done away from the centre.

HOME-KITS

Home-kits for teaching chemistry have been known for some time (for example see Minilab kits from Israel, the Chem-Kit™ by learning Resources Unlimited Inc. of Colorado, USA and the RADMASTE kit from South Africa [6]). These kits focus on particular practicals that are done in conventional university instructional laboratories and often use the same chemicals. Here we create redesigned micro-scale equipment that mimics that used in a formal laboratory. Only some of the experiments in programmes in science education for teachers use easily accessible materials [7, 8].

Our focus however is on teaching some of the basics of chemical engineering/industrial chemistry in the undergraduate curriculum through home practical kits. The entire formal set-up is redesigned and shown to be effective in micro-scale.

HOME-PRACTICALS

As much as possible, the materials chosen for home-practicals are commonly available in the student's neighbourhood. Any material, such as silica gel, that is not readily available to the student is sent in weighed amounts observing safety requirements. Home-practicals involving crystallisation, distillation, adsorption, extraction, filtration, sublimation, fermentation, electrodeposition, and various types of chromatography have been presented elsewhere [2, 9]. The home-practicals discussed here first evolved as lecture-demonstrations for conventional courses in reactor design and pollution control equipment design. They are as follows:

1. Fluid flow
2. Reactors
3. Centrifugal filtration
4. Water treatment

These four redesigned experiments, which we use for a chemical engineering course, are briefly explained below:

Fluid flow

- *Demonstration of laminar and turbulent flow for calculation of Reynold's number:* Injecting a solution of dye into water flowing through a tube has been used to explain laminar or turbulent flow [10]. For the home experiment this procedure was adapted using a saline delivery assembly with a 1-m tube and a disposable syringe containing potassium permanganate/ink solution (exp. 1). The flow rate is calculated as the time taken for 100 mL to flow out. The density and viscosity of water at ambient temperature are given.
- *Computing flow rates using a model centrifugal pump:* A model of a single-stage, single-suction open volute centrifugal pump was made using the head of a tabletop coconut scraper as the rotor (exp. 2, Fig. 1). The manual rotations per minute are plotted against the flow rate. Since the pump is manually rotated, only the average speed may be computed. Further the rpm cannot be fixed at uniform intervals when hand-rotated. However, over a range of average speeds, graphs may be obtained relating speed to the mass/volume centrifuged out. A typical student-graph obtained in our experiment is shown in Fig. 2.
- *The effect of particle size and flow rate in flow past packed beds:* A syringe assembly used for mimicking a hand-pressure liquid chromatograph [9] is packed with 5 g powdered chalk/column chromatographic grade silica gel of

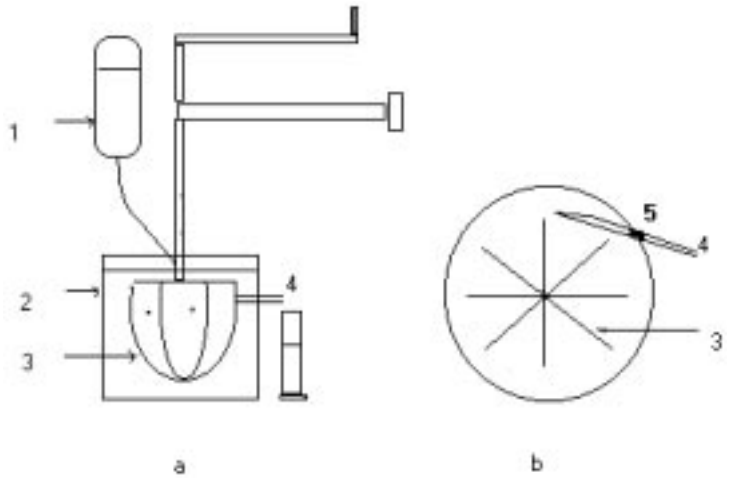

Fig. 1. (a) Hand-model of a centrifugal pump and (b) its cross-sectional view. (Legend: 1. Saline delivery assembly; 2. Plastic bottle; 3. Coconut scraper; 4. Pen shell; 5. Fitting rubber tube to prevent leakage.)

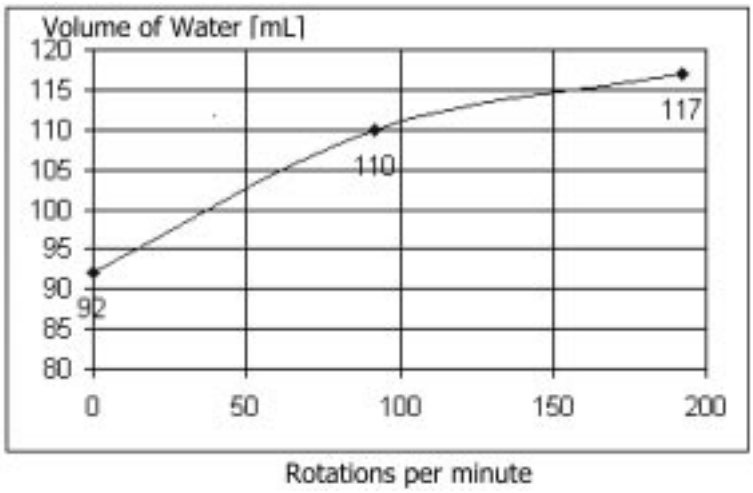

Fig. 2. The variation of volume centrifuged (mL) with respect to the rotations per minute of a typical student-model of the centrifugal pump.

known mesh size. The fluid is fed by syringe into the lead tube. The effect of varying fluid flow rate on the bed is observed. Keeping the velocity of the flowing fluid at the minimum, the column is now very slowly lengthened by withdrawing the upper piston to the maximum limit without disturbing the bed. The flow is increased in stages very slowly. At each stage the bed characteristics and finally the flow rate needed for the beginning of fluidisation are observed.

When chalk particles were used as the column packing material much pressure was needed to hand-pump the fluid through the bed. The bed arched and was damaged when fluid ascended with force. Increase in pressure made the particles crumble. Chromatographic-grade silica gel gave good results. Acid-washed (using battery acid) sea sand sieved between two different mesh-sized sieves (e.g. tea strainer and flour sieve) was used when silica gel was not available. The behaviour of the beds were compared.

Reactors

Models of the three ideal reactors are used to determine some design factors such as:

- Batch reactor-rate constant of an iodometric reaction
- Continuously stirred tank reactor-percentage conversion in urea hydrolysis during a fixed time
- Tubular reactor-reaction order of an iodometric reaction.

Centrifugal filtration

Powdered chalk pulverised in a blender is sedimented on a hand-model of a bottom-driven basket centrifuge. The weight and/or quality of the precipitate are used to determine the moisture content of the cake.

Water treatment

A sample of impure water is purified by alum flocculation and the quality is tested by microbiological colony count and BOD/COD estimations.

Thus we found it is possible to design home-kits for distance-student use based on some of the equipment used in the conventional undergraduate curriculum of chemical engineering.

EXPERIMENTAL SECTION

This section describes in greater detail the four experiments mentioned above and their associated home equipment. Chemicals such as potassium permanganate (Condie's crystals), sulphuric acid (battery acid about 3.75 M), copper sulphate and urea were available locally, while sodium thiosulphate, potassium iodide and ferric nitrate were sent to students in weighed amounts close to the theoretical amount and the required dilution specified on the zip-lock pack (two packs are used for packing each quantity [2]).

Experiment 1a: Nature of fluid flow and the measurement of flow rate

A hole of suitable diameter to insert a water tap tightly is cut in the bottom of a saline bottle. A saline tube 1.5 m is attached to it in the normal fashion. A 1-m length of this tube is fixed to a table with masking tape. The controller in the saline delivery assembly controls the flow rate. When the flow of water stabilizes at each velocity and after any air bubble in the tube has been removed, ink or a solution of Condie's crystals (25 mL) is injected very slowly into the center of the tube using a disposable syringe 1 m away from the open end. At low velocities streamline flow and at high velocities turbulent flow are observed. The flow rate as each phenomenon becomes apparent is determined as in Experiment 1b below.

The flow rate (in $m^3 s^{-1}$) of water flowing through a tube is determined by measuring the time taken for 100 mL to be collected using the set-up in Experiment 1a. The flow rate is further increased by using a model of a centrifugal pump (Fig. 1). The model is made as described in paragraph 1b that follows. The velocity is calculated by dividing the volumetric flow rate by the cross-sectional area of flow in the tube.

Experiment 1b: Centrifugal pump

The rotor of a tabletop coconut scraper is fixed with its rotor upside-down into a plastic bottle of at least 2 cm larger diameter at the widest. About 2–3 mm below and away from the broad end of the rotating head, a transparent ball-point pen shell containing a rubber tube is inserted sideways into the bottle wall 4–5 cm deep. The rubber ring is moved to the area that touches the bottle to get a tight fit. The broad end of the pen shell is cut at a 60° angle from the vertical (to the long-side) and the cut edge is inserted facing outside. The scraper axis and the bottle are attached firmly in position using wire. A saline tube leading from a saline bottle containing water is attached to the stationary axis of the scraper, to direct the flow to the axis of the rotor. With the water flowing at a rate fixed to maintain a constant level inside the bottle well above the blades (1 cm), the head is rotated at various speeds, (i.e. rotations per second) for 2 minutes by hand. The volume of water flowing out in this time is collected and measured using a syringe. The number of rotations per second is plotted against the volume displaced (Fig. 2). A model made, in which the removable rotor was inserted from the bottom of the casing, suffered from leakage and needed more skill to operate. Two persons are needed to operate this set-up.

Experiment 2: Reactors

Micro-scale models of the three ideal reactors are made as follows:

- *Batch reactor:* Iodometric titration involving the oxidation of iodide by hydrogen peroxide [12] was adapted for home experimentation with a glass jar as the batch reactor. Commercial hydrogen peroxide (6%) was diluted tenfold to make the reagent. 150 mL of (about 0.2 M) sodium thiosulphate ($Na_2S_2O_3$) solution is prepared by transferring (one home-kit pack of 4.8 g) $Na_2S_2O_3$ into a 250-mL glass jar and adding 150 mL of water. 500 mL of (0.02 M) KI solution is prepared by transferring about 2 g of the 4 g KI sent in the home-kit to a 750-mL bottle and adding 100 mL of water and then 20 mL battery acid slowly with stirring and then adding 380 mL water. The starch solution is prepared from sago (similar to tapioca starch granules) using the same procedure as for starch. Left over KI is used for standardising the commercial peroxide solution. A disposable syringe is used for quantitative transfer of the reagent. The plot of log concentration of peroxide against time needed for the appearance of blue colour after the addition of each 2 mL thiosulphate is obtained to find the rate constant.
- *Continuously stirred tank reactor (CSTR):* A CSTR model is made with a 50 mL plastic disposable syringe (Fig. 3). The stirrer is made from the piston of the syringe and rotated using a toy motor. The needle end of a 50 mL plastic syringe is sealed by flame heating. A hole of diameter 3 mm to fit a 2 cm piece of an empty plastic ballpoint pen refill is made just above the given scale with a heated iron nail. The refill tube is fixed to the hole with super-glue. A stirrer is made with a piston from a smaller syringe (25 mL) as follows: the black rubber piece and 1 cm of the blades from this end are shaved off leaving a middle stem onto which an empty plastic refill is glued. The rotor of a toy motor is inserted into the free end of the refill. The length of this arrangement should be suitable to stir the solution well. The motor is set up directly above the syringe's mouth. A penlight battery (size AA) is connected to the motor through wires when stirring is required. The reactants are fed from saline bottles through saline tubes from the top of the reactor (Fig. 3). The volume of the reactor is measured by filling it and allowing for overflow upon stirring. Flow rates are set such that the hot water flows at 7 mL per minute. Water from a tap is passed through a U-shaped copper tube kept in a boiling metal can. The metal tube is connected to the tap using a rubber tube and to the inlet saline tube tightly using wire. The urea solution (10 g/750 mL, about 0.22 M) is introduced at the rate of 3 mL/min into the reactor. Every 30 minutes, 5 mL of the product flowing out is taken up in 5 mL of battery acid diluted to 0.05 M, and titrated with standardised caustic soda with shoe-flower or morning glory flower extracts as indicator [2, 10]. The conversions are calculated for reactions of 60, 90 and 120 minutes.
- *Tubular reactor:* Two saline delivery assemblies are suitably connected to a Y-tube connected to a length of saline tube (Fig. 4). An iodometric reaction with varying amounts of thiosulphate is run. The distance required for the appearance of colour for each concentration is measured and the order of the reaction computed.

The rate constant for the reaction of ferric ions with iodide ions is investigated using a tubular reactor. This reaction is faster but more expensive to run than the reaction of iodide with peroxide (Expt. 1b) which also can be investigated with this set-up. The tubular reactor is constructed as follows. Two saline bottles are hung at the same level. An area of 2 cm × 2 cm is cut off from the hanging end of the saline bottles.

The saline tubes attached to each bottle is connected using a Y- or T-tube [2]. The Y-tube is

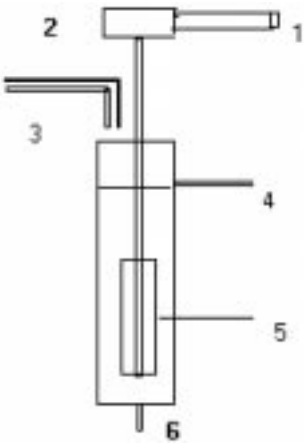

Fig. 3. A CSTR model. (Legend: 1. Penlight battery; 2. Toy motor; 3. Inlets; 4. Outlet; 5. Stirrer; 6. Sealed end.)

made by heating gently a transparent empty plastic ball point shell in the middle to form a small hole using a candle, bending the portion above by about 45° and quickly inserting the broad end of another similar shell. It is carefully tested to ensure that there are no leaks. A third saline tube is connected to the free end of the 'Y' tube. The whole length of this tube (item 3 of Fig. 4) is placed horizontally on a table using masking tape. The solution coming out at the end of the tube is collected (item 4 of Fig. 4). The cross-sectional area of the saline tube is calculated from its radius. The flow rates from each of the two bottles are determined by finding the time needed for 100 mL of each solution to flow when the controllers are fully open. 50 mL of water is placed in each saline bottle by means of a syringe when the flow controllers over the tubes are closed tightly. The controllers are then fully released and the stop-watch started simultaneously. The time required for the flow of 100 mL of water from the two saline bottles is measured. The cross-sectional area of the tube is calculated.

The following solutions A, B and C need to be prepared for the experiment:

- *Solution A:* 25.0 mL of 0.4 M KI solution is prepared by dissolving the given packet of KI salt (about 1.65 g) in 10.0 mL of water in a glass tumbler. 10 drops of a starch solution (prepared from sago—a granular starch similar to tapioca) is added and the solution made up to 25 mL.
- *Solution B:* 50 mL of 0.2 M $Na_2S_2O_3$ solution is prepared by dissolving the given packet of $Na_2S_2O_3$ salt in 50 mL of water.
- *Solution C:* 50 mL of 0.1 M $Fe(NO_3)_3$ solution is prepared by dissolving the given packet of $Fe(NO_3)_3$ salt in 50 mL of water.

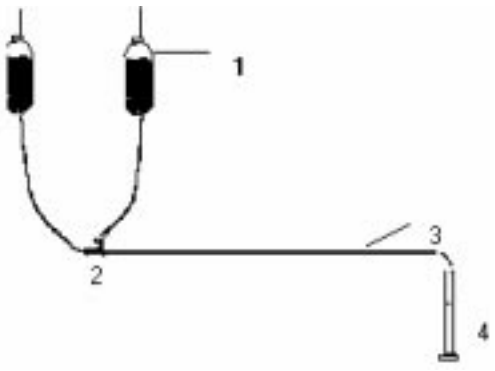

Fig. 4. Model of a tubular reactor for iodometric reaction. (Legend: 1. Saline bottle; 2. Y tube; 3. Saline tube; 4. Collecting vessel.)

To run the experiment, 40 mL of A, x mL of B and (5–x) mL of water are mixed in a separate glass tumbler. x is varied between 1 and 5 mL for different readings. This mixture is placed in one saline bottle with the controller fully closed. 50 mL of solution C is placed in the other bottle. The controllers are released simultaneously. The transition where a blue colour appears first in the horizontal tube on the table is marked. The distance from the joint of three tubes to this mark is measured. The experiment is repeated for $x = 2$, 3, 4 and 5.

The results are summarized in Table 1. Table 2 gives the computations.

The flow rate is $1.612\ \text{mL s}^{-1} = 1.612 \times 10^{-6}\ \text{m}^3\ \text{s}^{-1}$. The cross-sectional area of the tube is $0.5 \times 10^{-6}\ \text{m}^2$.

Concentration of reacted

$$S_2O_3^{2-} = \frac{1}{2}\left[\frac{V \times 0.2 \times 10^{-3} \times 10^{-3}}{50}\right]$$

$$S_2O_3^{2-} = Fe^{3+}$$

The gradient of the graph in Fig. 5 is 2.5, giving us a rate constant of 2.5. The first pseudo-order rate constant is 2.5.

Experiment 3: Centrifugal filtration

Bottom driven basket centrifuges are made as follows: The shafts of 2.5 mL, 5.0 mL and 10 mL disposable plastic syringes are removed. The latter two barrels are cut to the height of the first. Holes are pierced at equal intervals on the barrels using a safety pin heated on a candle. The black rubber ring of each is inserted at the bottom of the barrel. Another is used as a cover.

A square muslin cloth of sufficient size is rolled up and inserted into each tube to cover the entire internal surface. The shaft of a toy motor is inserted into the tube at the needle end. A fitting piece of wire casing is necessary between the shaft and the wall of the 10 mL syringe to get a non-wobbling system. A barrel of a 50 mL syringe is

Table 1. Results from the tubular reactor

V $S_2O_3^{2-}$ (mL)	Distance (cm)
1.0	13.0
2.0	19.0
3.0	21.0
4.0	24.0
5.0	27.0

Table 2. Calculations from the tubular reactor

V $S_2O_3^{2-}$ (mL)	D (cm)	t (s)	Reacted $[Fe^{3+}]$	$[Fe^{3+}]_0 - [Fe^{3+}]$	$-\log([Fe^{3+}]_0 - [Fe^{3+}])$
1.0	0.13	0.0403	0.002	0.048	−1.3187
2.0	0.19	0.0589	0.004	0.046	−1.3372
3.0	0.21	0.0651	0.006	0.044	−1.3565
4.0	0.24	0.0744	0.008	0.042	−1.3767
5.0	0.27	0.0837	0.01	0.04	−1.3979

used as the casing. It is just held outside the rotating barrel to prevent being sprayed.

Water (2.5 mL) is fed before rotation is commenced and the motor is then connected to a penlight battery for 3 minutes. The cloth is removed and weighed. It is inserted back and the well-mixed feed of constant amount (chalk previously soaked and blended with water) is fed to the barrel through a saline tube attached to a syringe at each trial and rotated likewise. The muslin cloth with the sediment is weighed again. The difference in weight is calculated.

The wetness (moisture content) of the sediments is also observed. Better distribution of sediment on the filter is found when the basket is fed in the middle during slow rotation. (Since we are interested in relative weights rather than absolute weights, approximate weights may be obtained by making a scale and getting weights in terms of, say, number of grains of rice for which average weight is given).

Experiment 4: Water purification [13]

- *Aluminium sulphate: Pieces* of aluminium foil are warmed in a solution of copper sulphate (quarter teaspoonful/10 mL) in a hot-bath till the solution loses colour completely. The solution is filtered using a cloth. The water sample (250 mL) is treated with this solution (8 mL/250 mL sample) and filtered through 2 mL acid-treated river sand bed packed in a 10 mL syringe. The control sample is not treated with alum but filtered similarly.
- *Microbiological colony count:* Instead of yeast extract, nutrients and agar in standard agar plates, marmite, clear-soup cube and jelly moss are used. Buffer solution (Butterfield's) is made with potassium dihydrogen phosphate sent in the kit and pH is adjusted using caustic soda and testing externally with flower extract. Strict aseptic procedures are followed using a pressure cooker and candle for firing. A well-dispersed colony is obtained using a syringe fixed to a toy motor assembly as used for the reactors. Dilutions are made with syringes and home distilled water from a kettle connected to a continuously cooled tube. Sterilised and oven dried jam bottle lids are used as plates. For milk agar medium sterilised milk is added.
- *Chemical oxygen demand (COD)* [13]: Condies' crystals (potassium permanganate) are used for the oxidation procedure with coppersulphate as the catalyst and the determination of excess oxidant using sodium oxalate is followed instead of the dichromate.
- *Biological oxygen demand (BOD)* [14]: The standard procedures are followed. However the Manganese sulphate solution is prepared as follows: About 2 g of Condie's crystals (potassium permanganate) is dissolved in 10 mL home-distilled water and to this is added 15 mL battery acid. Thiosulphate (about 3 g in 10 mL water or oxalic acid) is added drop-wise till colour faintly persists after 30 s. The solution is added to the bottom of the water sample by using a syringe connected to a saline tube long enough to reach the bottom.

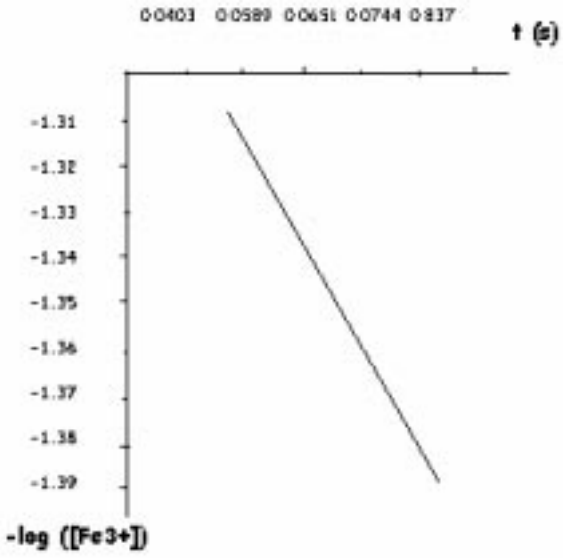

Fig. 5. Log of reacted Fe^{3+} against time.

The number of colonies in 1 mL of a milk sample = 217500 colony-forming units/mL. The oxygen demand is less for treated, filtered water: for kitchen effluent COD dropped from 32 to 18 mg/L while BOD dropped from 28 to 12 mg/L.

SAFETY REQUIREMENTS

General safety procedures need to be followed. All materials should be clearly labeled and kept away from the reach of children.

LABORATORY PERFORMANCE

Since home experiments are done without supervision and alone rather than in groups as in a

formal lab, allowance has to be made for it. For instruction, we film the experiments being done by us using a digital movie-camera and then load the clip with voice instruction on our website and also make it available on CD. This approach has been found to work well.

The absence of group-mates can always be overcome by getting help at home for such things as running the stopwatch. We in fact regard this independence as an advantage as students really have to know what they are doing whereas in a group environment, some students get away with simply recording the results while the others do the work. Further, since the students assemble their home-reactor models, they gain a much better grasp of the fundamentals.

CONCLUSIONS

It has been shown how usually expensive and laboratory-based experiments can be redesigned and done at home for teaching purposes, thereby increasing the distance experience and making distance education truly distant in some cases. As a sample, four experiments covering reactor design and pollution control equipment have been redesigned to show the use of locally available materials adapted for home-labs. Some of the chemicals needed are sent in weighed amounts in a home-kit. Home practicals allow those students who cannot take time off from duties and commitments to succeed by doing more of their laboratory work at home.

One of the authors, teaching at the University of Peradeniya's Engineering Faculty, is using these redesigned labs as lecture demonstrations in the lecture theatre to enhance teaching quality. Thus the same home kits also have their use in the conventional classroom.

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