



# IODINE VOLATILIZATION FROM IRRADIATED CSI SOLUTIONS

G.J. Evans and E.J. Panyan

## Abstract

A bench-scale, separate-effect, flow apparatus has been constructed to examine volatile iodine production rates in relation to a selection of the possible variables and conditions found in a containment structure with a breached reactor core. The constructed apparatus is designed to provide the widest possible range of data including gas and aqueous phase speciation for an established set of interfacial mass transfer parameters with known pH and dissolved oxygen levels.

As the interfacial transfer of iodine is an important component in the understanding of iodine chemistry, commissioning of the constructed apparatus focused on establishing a well characterized set of mass transfer parameters for a variety of mixing conditions and solution volumes. Aqueous phase parameters, obtained using a method involving the sparging of the dissolved oxygen in the aqueous phase, were found to vary by one order of magnitude, from  $1 \times 10^{-2}$  to  $1 \times 10^{-3}$  dm/sec. Gas phase parameters also changeable by one order of magnitude, from  $1 \times 10^{-1}$  to  $1 \times 10^{-2}$  dm/sec, were studied more thoroughly as they were found to have a greater impact in the system. Two independent methods of analysis were used, one involving tri-iodide solutions, the other using relative humidity values.

A selection of the acquired volatility rates in relation to the effect of pH are presented. The apparatus has been found to consistently provide rates up to one order of magnitude lower than modelled predictions. Specifically, for buffered solutions, rates of  $2 \times 10^{-12}$  mol/min and  $1 \times 10^{-10}$  mol/min for pH 9 and 5 respectively, have been found. Rates of  $1 \times 10^{-11}$  mol/min and  $6 \times 10^{-10}$  mol/min are predicted. Current efforts have addressed potential reasons for this apparent discrepancy, the major factor being the possible release of components from the stainless steel during irradiation.

Efforts undertaken to ensure the validity of the results are emphasized. During commissioning efforts, several problems have been identified and addressed including line losses, the efficiency of the gas phase measurement system, and the purity of the  $^{131}\text{I}$  tracer.

## 1. INTRODUCTION

The volatility of radioiodine following a reactor accident depends to a large extent on its aqueous chemistry. Radiation plays a dominant role in determining this chemistry, due to the numerous reactions that can occur between iodine species and the products of water radiolysis.

Due to radiolytic reactions, the form of iodine initially released into containment may not have a large impact on the long term volatility of iodine. [1,2]. In contrast, both pH and total iodine concentration play a substantial role in determining iodine volatility above irradiated solutions [1,2,3,4,5]. The overall importance of pH has been demonstrated in both bench scale [2,3,4,5] and intermediate scale experiments performed in the Radioiodine Test Facility (RTF) [1,6]. The role of total iodine concentration has been evaluated in bench scale experiments [3,4]. It is now suspected that at low total iodine concentrations and at high pH, iodine atoms may contribute substantially to iodine volatility [3]. Finally, many organics have been found to have a substantial impact on iodine volatility [1,6,7].

Over the last eight years, considerable progress has been made towards understanding the impact of radiation on iodine volatility, due to a large extent to the experiments performed at the RTF. However, evaluation of the radiolytic chemistry based on these integrated experiments alone can be difficult due to the many other phenomena involved such as interfacial transfer and surface adsorption rates. Supporting separate effects tests, based primarily on bench scale experiments, are needed in order to evaluate the roles of individual parameters. The impact of organics, for example, may be partially indirect, due to induced changes in pH and dissolved oxygen, and partially direct, due to scavenging of radicals or formation of organic iodides. Hence, investigation of the role of organics requires experiments in which pH and dissolved oxygen can be monitored or controlled independently.

This paper describes preliminary results from an ongoing bench scale study of parameters affecting iodine volatility in irradiated systems. Specifically, a bench scale apparatus has been constructed that allows continuous measurements of pH, dissolved oxygen, and the rate of iodine volatilization during irradiation of  $^{131}\text{I}$  labelled CsI solutions in a  $^{60}\text{Co}$  Gamma cell. This apparatus differs from similar systems [5] in that the solution is mixed during irradiation using known stir rates such that the rate of air/water interfacial mass transfer, and hence dissolved oxygen concentration, can be controlled. An accurate knowledge of the interfacial transfer rate is important as, during transients, this is the link between the amount of iodine in the gas phase and the liquid phase chemical speciation. The approach used in the present study also differs from previous work [2,3,7] in that the rate of iodine volatilization is being evaluated rather than the concentration of gas phase iodine or iodine partition coefficient.

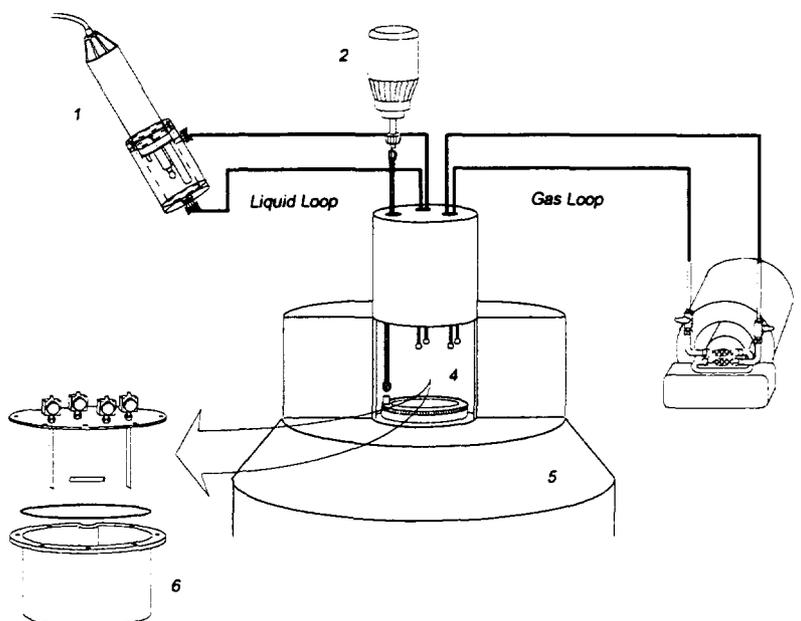
## 2. EXPERIMENTAL

### 2.1 APPARATUS

A pictorial representation of the main components of the constructed apparatus is provided in Figure 1. The centrepiece of this apparatus is a 0.85 L stainless steel irradiation vessel. This

vessel and a custom built magnetic stir plate are placed in the irradiation chamber of a Gammacell 220 which has a well known dose rate of 0.15 kGy/hr. The stir plate itself is connected to a mixer capable of varying the stir speeds (10 to 500 rpm) and consequently the interfacial mass transfer conditions inside the vessel. A stir bar, inside a stainless steel sleeve (5.0 cm in length, 0.5 cm in diameter) is used to mix the solution.

**Figure 1: Pictorial representation of the experimental set-up**



(1) Water analyzer, (2) Stir-plate mixer, (3) NaI detector with filter assembly (by-pass loop not shown), (4) Stir-plate inside the irradiation chamber, (5) Cut-away view of the Gammacell 220, (6) Unassembled irradiation vessel. (Note: gas phase pump, liquid phase pump, aqueous phase injection and extraction ports, and flow meters are not shown)

Four gas-tight, stainless steel, needle valves connect the irradiation vessel to gas and liquid phase recirculation loops made of a combination of 1/16" and 1/8" stainless steel tubing. Using a model 77390-00 peristaltic Masterflex L/S PTFE Tubing Pump and a PTFE pump head, the liquid loop transports the aqueous material inside the irradiation vessel to a 50 mL Plexiglas monitoring chamber outside the Gammacell at a rate of 10 mL/min. This custom built chamber houses an ICM Industrial Chemical Measurement water analyzer (model 51601), consisting of pH, dissolved oxygen and temperature sensors. Each value can be recorded at set time intervals ranging from two to thirty minutes depending on the dictates of the testing conditions.

Gas phase loop circulation is controlled with the use of a model DOA-P104-AA GAST diaphragm pump possessing a fixed flow rate of 0.07 L/sec. This allows the volatile material produced in the vessel to be transferred to a monitoring assembly consisting of species selective adsorbents -  $\text{CdI}_2$  and TEDA impregnated charcoal - and a Teledyne Isotopes, model S-88-1, 2x2 NaI detector using a Canberra Nuclear Products Group Accuspec multichannel analyzer (MCA) Card (model 07-0399). Two cartridges of each adsorbent, housed in 1/4" Tygon tubing, are used in series to trap the gaseous iodine species. As it was determined that the original system design did not allow a sufficient residence time for the

CdI<sub>2</sub> filters to function properly, a by-pass line, in which the gas phase flow rate was reduced to one tenth (7 mL/s) of the main line gas flow rate was created. It has been found that with this new assembly in which only the charcoal filters, located in the main loop, are monitored by the NaI detector, the retention efficiency of the first filter of each adsorbent is greater than 95%. Volatilization rates recorded by the detector are down loaded to a 286 Packard Bell computer for analysis. In an effort to minimize the risk of a volatile iodine release, the gas phase loop has been designed so that the only portion of system with positive pressure is that of the filtered gas.

Volatile iodine accumulation rates are determined through the use of <sup>131</sup>I and a NaI detector. The efficiency of this detector has been established to be approximately 4% with minimal variation between tests. Regardless, an LKB Compugamma system with a 3x3 well type NaI detector, calibrated monthly, is used to check the efficiency of the system detector for each portion of testing. It has been determined that due to the detection efficiency of the NaI detector in the system, a maximum of 0.2 mCi of <sup>131</sup>I is needed to detect volatilization rates as low as 1x10<sup>-13</sup> mol/min.

System temperature levels are not controlled but liquid phase temperatures have been found to stabilize at approximately 28 - 30 °C under irradiation conditions.

## 2.2 METHODOLOGY

A typical experimental run consists of the following process; a measured amount of water, typically 200 mL, is added to the vessel which is then sealed and connected to the recirculation loops. Prior to use, the water is purified using reverse osmosis with further purification through filtration and deionization using a Barnstead nano-pure system. This system includes a charcoal bed for removal of organic substances and is reputedly able to reduce the organic levels to 10 ppb. The gas tight seal of the vessel is achieved with a rubber o-ring which is assumed to contribute negligible contamination to the system. The o-ring is replaced at regular intervals to guard against radiation degradation. The gas and liquid phase pumps are then activated and the system pH is adjusted to the required level with the use of LiOH or H<sub>2</sub>SO<sub>4</sub>. For buffered solutions, a combination of 0.1 M mono potassium phosphate and 0.05 M Borax is used. This solution is effective for buffering pH levels spanning the range of 5.8 to 9. The vessel is then lowered into the irradiation site and the stir plate motor is engaged to establish the desired mass transfer conditions. Using Aldrich 'Gold Label' CsI and Merck Frosst 'carrier free, reducing agent free' <sup>131</sup>I, a measured amount of 2.5x10<sup>-3</sup> M iodide solution is added to the system, through an injection port in the liquid phase line to produce the desired 1x10<sup>-5</sup> M iodide concentration in the vessel. Depending on the test conditions, a known amount of organic may also be added at this time. Dissolved oxygen, pH, temperature and gaseous iodine levels are subsequently monitored on a continuous basis. Liquid phase organic iodide levels are determined at selected time intervals using five mL extracted samples and various separation techniques. The extracted samples are also checked for: 1) total iodine activity to determine the total liquid phase iodine concentration; 2) the pH with a model 9172BN, Ag/AgCl Sure-Flow Electrode external probe; and 3) iodide levels with a model 90-02, Double Junction Reference Electrode for Bromide and Iodide.

To ensure the reproducibility of results and the accuracy of various measurements, several pre-test calibrations and quality assurance procedures are performed: the on-line pH and

dissolved oxygen probes are calibrated prior to every test; flow meters used in the gas phase loops are periodically recalibrated; and all the reagents used are weighed out using a calibrated OHAUS Electronic Balance (model TS 120S) with three digit accuracy. Calibration of the scale is conducted on a monthly basis using calibration weights.

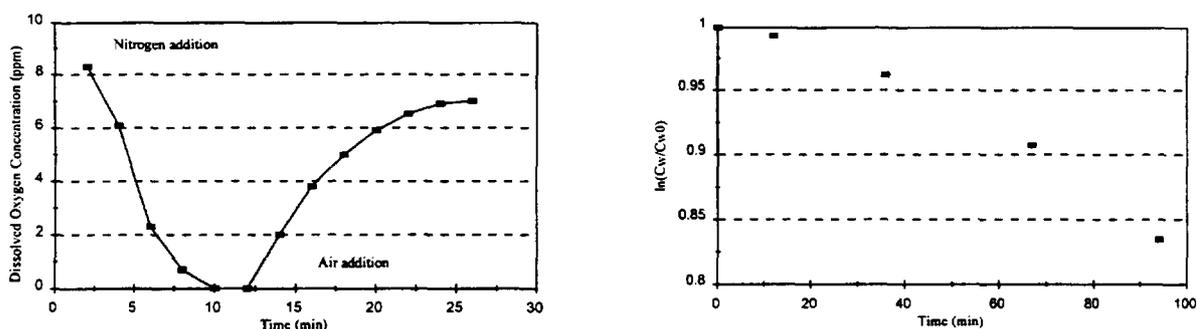
Finally, several post-test procedures are implemented to both calculate an activity balance at the end of each test and to clean the system for subsequent testing. Cleaning procedures include rinsing all interior surfaces of the apparatus with a 5% nitric acid solution, followed by rinsing with purified water.

### 3. PRELIMINARY RESULTS AND DISCUSSION

During commissioning of the apparatus, a number of experiments were performed to determine the interfacial mass transfer rates for various aqueous volumes and stir speeds.

Aqueous phase testing involved the following procedure; a measured amount of deionized water was added to the vessel which was subsequently sealed and placed on the stir plate. A combination of 1/8" stainless steel tubing and Tygon tubing was used for the liquid phase line. This line connected a peristaltic pump, set at approximately 10 mL/min, and the water analyzer, housed in its Plexiglas chamber, to the vessel. Upon achieving a steady state dissolved oxygen (DO) level of about 8 ppm, nitrogen gas, added through one of the two open gas phase ports, was used to sparge the liquid. When a DO level of 0 ppm was attained, the nitrogen supply was removed and a step change addition of compressed building air was added to the gas phase in the vessel. The resulting DO trend was recorded at intervals ranging from one to ten minutes depending on the conditions selected for the run. Of note is that the area of the interfacial surface was not a constant value due to vortex formation especially at the higher stir rates. A value of 0.1 dm<sup>2</sup> has been estimated for stagnant conditions based on the vessel geometry. A typical trend obtained during the above testing is provided in figure 2.

**Figure 2: Typical trends obtained during mass transfer calibration testing**



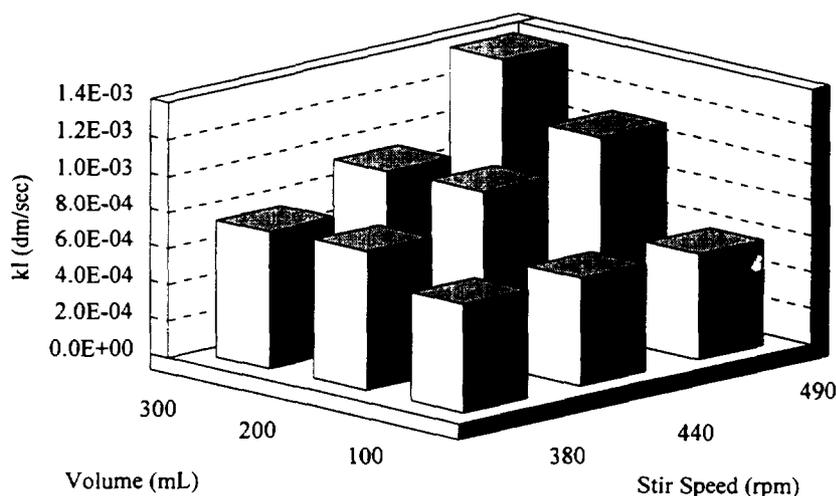
The graph on the left is the trend produced with the aqueous phase mass transfer procedure. The graph on the right displays a trend produced with the gas phase procedure. Both correspond to conditions of 200 mL of solution at a stir rate of 380 rpm.

Gas phase mass transfer coefficients were originally found using a titration method and an I<sub>3</sub><sup>-</sup> solution produced by mixing saturated I<sub>2</sub> and KI solutions. In another study, the transfer of I<sub>2</sub> from I<sub>3</sub><sup>-</sup> solutions has been found to be limited by the gas phase resistance alone due to the

rapid equilibrium between  $I_2$  and  $I_3^-$ . A measured volume of the  $I_2/KI$  solution was added to the vessel which was then placed on the stir-plate in order to provide the selected amount of mixing for the solution. The vessel was left open to ensure the concentration of  $I_2(g)$  was negligible. At various time intervals, five mL samples were taken from the vessel. Titrating this sample with a standardized 0.005 M sodium thiosulphate solution provided the desired trend also shown in Figure 2.

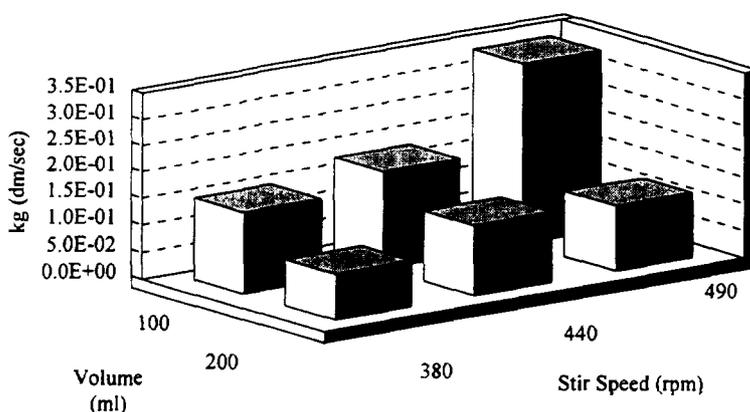
The regions of high mass transfer (high stir speed, low volume) were more thoroughly investigated than those of low mass transfer (high volume, low stir speed). This selection was based on an effort to determine the mass transfer coefficients for the conditions with the greatest impact on iodine volatility. This region was also selected to be the first explored in subsequent tests to determine the upper achievable limits of the system.

**Figure 3: A selection of aqueous phase mass transfer values as a function of mixing rate and aqueous phase volume**



Above is a selection of the experimentally determined, aqueous phase mass transfer coefficients. The values were obtained by varying the volumes and the stir speeds inside the vessel. Each data point was the average of two runs. Agreement between replicates was within 10%.

**Figure 4: A selection of gas phase mass transfer values as a function of mixing rate and aqueous phase volume**

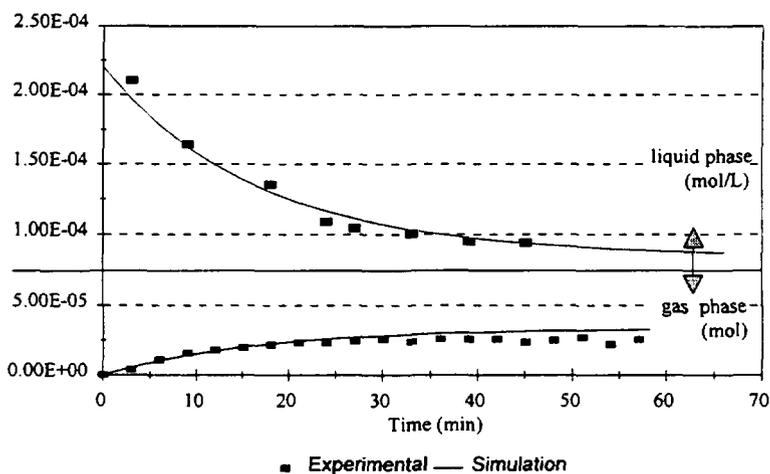


Above is a selection of the gas phase, transfer coefficients determined using the  $I_3^-$  method.

Results of the testing indicated that an order of magnitude difference in both gas and liquid phase mass transfer parameters is obtainable with the designed equipment. This implies the designed system is capable of supplying a wide range of mixing conditions. Figure 3 and 4 provide the mass transfer parameters found in the high mass transfer region of interest. The low mass transfer region (low stir speeds and high volumes) which was also investigated, indicated that values on the order of  $1 \times 10^{-4}$  dm/sec were obtainable for the aqueous phase while the lowest gas phase coefficient found was  $4.5 \times 10^{-2}$  dm/sec.

In order to evaluate the reliability of the apparatus, an experiment was performed using 200 mL of an  $^{131}\text{I}$  labelled, non-irradiated  $\text{I}_2$  solution buffered at pH 5. This test allowed the mass transfer parameters, the potential for line losses and the gas phase iodine measurement system to be evaluated. The experimental results agreed well with the expected rate of  $\text{I}_2$  transfer to the gas phase indicating that line losses were not significant. In addition, the  $\text{CdI}_2$  on chromosorb P used for adsorbing  $^{131}\text{I}_2(\text{g})$  in the by-pass loop was found to be over 95% efficient. However, approximately 20% of the iodine remained in solution at the end of the test, rather than being transferred to the trap. Analysis revealed that this iodine was in the form of  $\text{I}^-$ . The apparent reduction of  $\text{I}_2$  to  $\text{I}^-$  was attributed to a reaction induced by the stainless steel surfaces. A pseudo first order rate constant was determined for this reduction mechanism ( $4 \times 10^{-4} \text{ s}^{-1}$ ) and found to be negligible as compared to the rate of radiolytic reduction of  $\text{I}_2$ . However, in subsequent experiments the stainless steel vessel was found to substantially decrease the rate of iodine volatilization from irradiated solutions. Figure 5 provides a typical set of results for the above testing conditions.

**Figure 5: Volatilization from a  $1.1 \times 10^{-4}$  M  $\text{I}_2(\text{aq})$  solution with no irradiation**



The above test was performed at a pH of 5 with buffered water. The computer simulation and experimental data agree when the suspected overall reaction mechanism, due to interaction with the stainless steel surfaces, is included. Of particular note is that the mass transfer in the system is predicted correctly.

As the stainless steel vessel was found to interact with the iodine, the validity of the previously obtained gas phase mass transfer values was questioned; these values were determined with a method that assumed that the vessel had a negligible impact on the system. A second method for determining gas phase parameters was conducted in order to eliminate this doubt and also served to further improve the understanding of the mass transfer conditions studied. This method involved measuring the change in relative humidity of air

passed through the vessel. The rate of evaporation of water, which is directly proportional to the gas phase mass transfer coefficient, could thereby be determined based on the change in relative humidity and the known flow rate of air. The gas phase line was modified to accommodate two Cole Parmer Tri Sense Relative Humidity and Temperature probes (model 37000-50), one placed at each end of the opened loop. The change in relative humidity was determined for various stir rates, air flow rates and volumes of liquid in the vessel. By monitoring both the temperatures and relative humidities at these positions, the gas phase interfacial parameters were determined. Results, as presented in Table 1, correspond well with the previously presented values. Discrepancies in the comparable conditions are within a factor of two which is within an acceptable error limit considering the differences in the methods. In particular, the relative humidity method is more susceptible to the effects of splashing than that of the tri-iodide method. At a volume of 100 mL this effect is readily apparent. It should be noted that for volumes of 200 mL and greater,  $k_g$  was not greatly affected by the stir rate. In particular no effect was observed for a 500 mL volume. In general, stirring would not be expected to impact significantly on  $k_g$  as most of the gas mixing is likely to be due to the flow of air into the vessel. The small impact observed for smaller volumes was likely due to an increase in the interfacial area.

**Table 1: Experimentally determined gas phase mass transfer values, in units of dm/sec, using the relative humidity method**

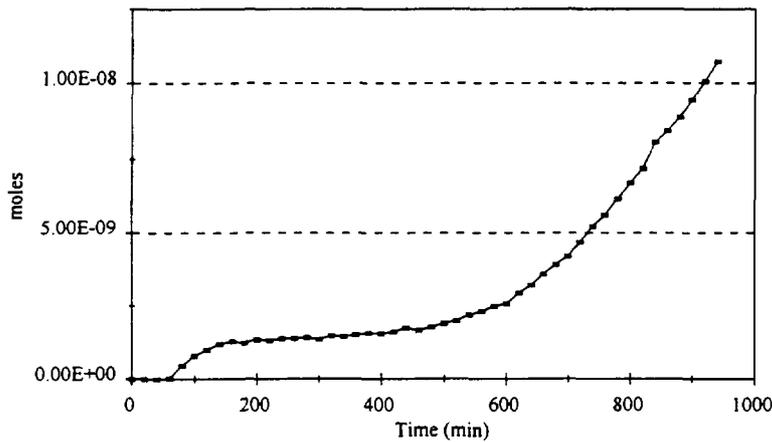
|            | volume | 100 mL             | 200 mL             | 300 mL             | 500 mL             |
|------------|--------|--------------------|--------------------|--------------------|--------------------|
| <b>rpm</b> |        |                    |                    |                    |                    |
| <b>0</b>   |        | $1 \times 10^{-1}$ | $5 \times 10^{-2}$ | $8 \times 10^{-2}$ | $8 \times 10^{-2}$ |
| <b>110</b> |        | --                 | --                 | --                 | $8 \times 10^{-2}$ |
| <b>160</b> |        | --                 | --                 | --                 | $8 \times 10^{-2}$ |
| <b>380</b> |        | $4 \times 10^{-1}$ | $6 \times 10^{-2}$ | $1 \times 10^{-1}$ | $8 \times 10^{-2}$ |
| <b>440</b> |        | $6 \times 10^{-1}$ | $7 \times 10^{-2}$ | $1 \times 10^{-1}$ | $8 \times 10^{-2}$ |
| <b>490</b> |        | $1 \times 10^0$    | $8 \times 10^{-2}$ | $1 \times 10^{-1}$ | $8 \times 10^{-2}$ |

Further commissioning of the apparatus involved the use of computer simulations. In particular, the theoretical effects of altering the gas flow rates were explored. It was determined that the selected flow rate of 0.07 L/sec would be adequate in ensuring the volatile iodine would not accumulate in the gas phase above the liquid. The model also predicted that under such a design setting, volatile iodine accumulation would be suppressed until the hydrogen peroxide in the system achieved steady state. Experimental results have corroborated this prediction as observed in figure 6.

Figure 6 also indicates the ease with which discrepancies between modelled and theoretical results can be quickly recognized and scrutinized for validity. For example, there is an immediate and unpredicted rise in the gas phase iodine levels at the time of initial exposure to radiation. Subsequent analysis revealed that this gas phase spike was due to small amounts of a volatile iodine contaminant, possibly organic iodide, in the tracer. This spike was also observed in a test performed without radiation, indicating it was not a result of radiolytic

reactions. It has been determined that the spike can be minimized by purging the tracer solution with air prior to use.

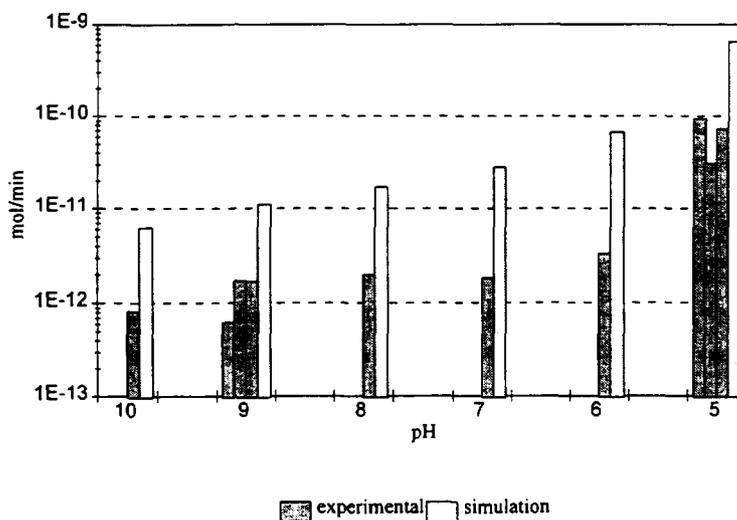
**Figure 6: Volatilization of iodine from an irradiated  $1 \times 10^{-5}$  M CsI solution with pH 5**



Initial iodine volatilization from 200 ml of a  $10^{-5}$  M CsI solution buffered at pH 5. Shown is the number of moles of iodine accumulated on the charcoal filter assembly as a function of time, the slope of which is the volatilization rate. At time 75 min, the solution is exposed to radiation and a spike is observed in the gas phase levels. This is not predicted by computer modelling and it is believed to be due to a contaminant in the tracer. At time 500 min, the volatilization of iodine became significant. Computer simulations indicate that approximately 400 min would be required for hydrogen peroxide to reach steady state.

One portion of the proposed experimental test matrix involved an examination of the effect of pH on the volatility of iodine. Performing such a test served a twofold purpose: 1) provide an indication of the experimental reproducibility of the results; and 2) since the data on the behaviour of this portion of iodine chemistry is fairly well established it was anticipated it would provide an estimate of how well the results for this apparatus agree with model predictions. Typical results are provided in figure 7.

**Figure 7: The effect of pH on iodine volatility**



Presented results are experimentally obtained and those predicted by computer simulations. An example of reproducibility is also provided for two key pH levels of 9 and 5.

The expected trend of increased volatility rates with decreasing pH are found but there is a consistent discrepancy between the experimental and theoretical results. Experimental results are up to one order of magnitude below the expected rates. The computer simulations were performed using a set of approximately 60 reactions that had previously been found to give good agreement with measurements of the steady state iodine partition coefficient [3]. It should also be noted that this reaction set also gave reasonable agreement with the experiments performed by Sims et. al. under acidic conditions [5]. For example at a pH of 4.6 and a dose rate of 0.26 kGy/h, Sims et. al. observed a volatilization rate of  $7 \times 10^{-11}$  mol/min while a value of  $2 \times 10^{-10}$  mol/min was predicted by our model for his experimental conditions. However, at pH 7 Sims et. al. observed a rate of  $5 \times 10^{-12}$  mol/min while our model predicted  $3 \times 10^{-11}$  mol/min. Hence some discrepancies in the estimation of volatilization rates under basic pH conditions may still exist. In particular, in our reaction set iodine atoms are assumed to be volatile which substantially increases the volatilization rates predicted for pH values above 7. For example at pH 9 the predicted volatilization is  $1 \times 10^{-11}$  mol/min whereas if only  $I_2$  is assumed to be volatile (i.e. iodine atoms are assumed to be non-volatile) the predicted volatilization rate would be  $1 \times 10^{-13}$  mol/min. At a pH of 7, under the conditions used by Sims et. al., a volatilization rate of  $3 \times 10^{-13}$  mol/min is predicted if the iodine atoms are assumed to be non-volatile, as compared to the value of  $3 \times 10^{-11}$  mol/min with volatile atoms. It is clear that the values predicted with volatile iodine atoms are much closer to the experimental results which supports the belief that the volatility of iodine atoms should be included in the model. It may be that the discrepancy under basic pH conditions is due to the omission of a mechanism for reducing iodine atoms in the model [3].

Considerable effort was invested in evaluating the factors that might be decreasing iodine volatilization rates in our apparatus. The first potential cause investigated involved the interior surfaces of the apparatus, in particular the stainless steel. Iodine is known to be adsorbed by such surfaces in quantities which depend on the conditions of the test itself; adsorption at high humidity and ambient temperature is known to be quite rapid. Activity balances conducted at the end of each test indicate that the gas phase surfaces are more of a problem than the liquid phase surfaces in this respect. In total, during a typical run, about 10% of the available iodine may be captured by the stainless steel surfaces. The amount of iodine retained by the gas phase lines was evaluated after every test by washing the lines with concentrated  $Na_2S_2O_3$  followed by  $HNO_3$ . However, the amount of activity in these wash solutions was generally small as compared to that on the charcoal trap indicating that gas phase line losses were not significant. The second potential cause, which was found to be minor in comparison, involved a reaction between the stainless steel and the iodine itself. Tests conducted in the absence of a radiation field with a saturated molecular iodine solution (see figure 5) indicated that a detectable portion of the iodine remained in solution instead of volatilizing. However, the rate of  $I_2$  reduction due to reaction with the steel was small as compared to the rate of  $I_2$  reduction through radiolytic mechanisms. Other potential causes that were evaluated were the  $H_3PO_4$  buffer, materials originating from the charcoal traps due to the recirculation of the gas phase and the dissolved oxygen probe (which contains an ethylene glycol solution). All of these were found to have no significant impact. However, replicate experiments revealed that the volatilization rate under a given pH was decreasing as more experiments were performed. It was suspected that corrosion was occurring within the stainless steel vessel or lines resulting in the release of material into solution that affected the radiation chemistry. A glass insert for the irradiation vessel is being constructed to investigate this hypothesis.

## 4. CONCLUSIONS

The initial efforts involved in the commissioning of a bench scale apparatus for the study of iodine volatilization from irradiated CsI solutions have been described. An essential component of these commissioning efforts was the establishment of the interfacial mass transfer characteristics. It was found that the aqueous phase mass transfer parameter could be altered by one order of magnitude ( $1 \times 10^{-3}$  to  $1 \times 10^{-4}$  dm/sec) for a set of well defined volumes and stir rates. The gas phase parameter, recognized as having the larger impact on iodine volatility in this system, was studied in greater depth using two independent methods of analysis. Depending on the selected aqueous volume and stir rate, it was found that this parameter could also be varied by one order of magnitude ( $1 \times 10^{-1}$  to  $1 \times 10^{-2}$  dm/sec) and the agreement between the results obtained with the different methods has provided a reasonable level of confidence in their accuracy.

The apparatus is currently being used in an ongoing study of iodine volatilization rates. In particular, the recent results on the effect of pH on iodine volatility were presented. It was found that the model consistently predicted higher levels of iodine volatility than those found experimentally. Further testing of the reliability of the apparatus indicated that there are several potential causes for this rate suppression, the major factor being the stainless steel surfaces of the vessel.

Finally, the computer simulation used to model the apparatus has proven to be an invaluable tool in the development of the system. It is anticipated that the ability to independently vary mass transfer rates, pH, dissolved oxygen and organic concentration using this system will provide novel data that will greatly assist in the further development of this model.

## 6. REFERENCES

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