Risk Assessment for Chlorine Dioxide Systems

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Paper presented at
PSLM 2005, Toronto, Ontario
October 16-19, 2005

Abstract

Chlorine dioxide has been in use as a bleaching agent in the pulp and paper industry for over fifty years. Superficially, at least, its hazards are well known; in practice, we have had some situations whose root causes must be eliminated.

Technological evolution over that half century has largely been focused in two areas: upstream on its generation process, where using methanol as the reductant has essentially eliminated sulphur dioxide, and downstream on its reaction with the pulp stream, where increasing use of ClO_2 has essentially displaced molecular chlorine, removing another hazard concurrently, and the evolution of design of the reactor towers has advanced to suppress gas release while incorporating variable retention time for flexibility.

This paper reviews the basic processes used for ClO_2 production: both the early vintage atmospheric generators such as the R2, Mathieson and Solvay processes and also the more recent vacuum generator-crystallizer effluent-free technology using the same chemical reactions. We also discuss the evolution in reaction tower design from the standpoint of gas containment and operational flexibility.

We then turn to the intermediate storage facility for chlorine dioxide solution, between absorption and application, which poses a significant process safety risk, one that requires sharp attention. An overview of major findings from a series of risk assessments undertaken with the involvement of one of the authors in nine Canadian pulp mills is then presented. The findings include lapses in process safety management systems, cultural issues, and quantitative information regarding potential consequences of unintentional ClO_2 releases from containment.

Historical Evolution of Generation Technology: Part I

Chlorine dioxide was first uniquely identified as a strong oxidant about 150 years ago but it took nearly a century to develop a real need for it and the technology to produce it on a commercial scale. During, and shortly after, World War II, three chemical companies, in three countries, developed production scale systems in parallel and almost simultaneously. All three processes used sodium chlorate as the oxidant, although sodium chlorite had been tried, and potassium chlorate would certainly be workable, although more costly.

Mathieson Chemical Company in the United States developed a process in 1944 using sulphur dioxide to reduce the sodium chlorate. It was commercialized in 1950 before Mathieson merged with Olin Corporation in 1954. This process generates

chlorine dioxide (ClO_2) by the reduction of sodium chlorate ($NaClO_3$) with sulphur dioxide (SO_2) in the presence of sulphuric acid (H_2SO_4).

$$2\ NaClO_3 + SO_2 \text{ --> } 2\ ClO_2 + Na_2SO_4$$

In Belgium, Solvay S. A. developed comparable scale equipment, using methanol as the reductant. The Solvay process equipment looks essentially the same as the Mathieson system.

$$4\ NaClO_3 + H_2SO_4 + CH_3OH \text{ --> } 4\ ClO_2 + 2\ Na_2SO_4 + HCOOH + 3\ H_2O$$

In Canada, a third near-simultaneous development was being carried out by the Electric Reduction Company (Erco). Their first process, the R1, used sodium chlorate and sodium chlorite which reacted in strong acid to form chlorine dioxide. This is the first of the "R" processes developed by the late Dr. Howard Rapson. Much more successful commercially however, was the R2 which followed a short time later and is based on the use of sodium chloride (NaCl) for reducing the sodium chlorate.

$$NaClO_3 + NaCl + H_2SO_4 \text{ --> } ClO_2 + \tfrac{1}{2}\ Cl_2 + Na_2SO_4 + H_2O$$

All three processes employ concentrated sulphuric acid to provide the required low pH and air is used for agitation of the reactor and for dilution of the chlorine dioxide gas to suppress concentration below the explosive limit. Similarly, all three discharge a liquid byproduct stream that is highly acidic and rich in sodium and sulphur compounds, making it useful as a makeup stream to the pulping liquor cycle.

With chlorine dioxide utilization in pulp bleaching at 5-10 kg/tonne of pulp, the byproduct liquid stream could still be utilized in all but the most tightly closed process cycles. A number of companies, including Hooker Chemical, Erco Industries and Anglo Paper Products began to work on alternatives to eliminate the significant acidic liquid stream which required neutralization. The answer was vacuum crystallization and a new generation of generator crystallizer processes emerged.

Historical Evolution of Bleaching with Chlorine Dioxide

The bleached kraft pulp industry was in its infancy until about 1950 and the chemicals used to oxidatively brighten pulp were chlorine gas (Cl_2) and sodium (or calcium) hypochlorite (NaOCl, $Ca(OCl)_2$). A typical bleaching sequence, using our industry jargon, was CEHEH where C means molecular chlorine, E means sodium hydroxide extraction and H means hypochlorite.

The first step in application of chlorine dioxide was to take advantage of its higher selectivity in the final brightening in a sequence such as CEHED in which 5-7 kg chlorine dioxide/tonne of pulp displaced a stoichiometrically equivalent hypochlorite usage. D designates a chlorine dioxide stage.

These bleach plants were often retrofits or early generation facilities using downflow chlorine dioxide bleaching towers. The problem with downflow towers, suitable for less volatile chemicals, was that they gas off through inadvertent air stripping as the pulp stock freefalls from the top inlet down into the tower. Gas-rich vapours escaping from chute connections caused gas concentrations ranging from uncomfortable to unsafe within the enclosed buildings we use in our industry in Canada.

The next step in chlorine dioxide technology evolution was splitting chlorine dioxide reagent addition into two steps, still retaining hypochlorite bleaching. This sequence, CEHDED was installed at Crofton, BC and Hinton, AB in 1957. These configurations used only slightly more chlorine dioxide, 7-10 kg chlorine dioxide/tonne of pulp, and were successful in displacing still more hypochlorite.

The ultimate step in boldness was to eliminate hypochlorite bleaching entirely and attain full brightness kraft softwood, using only molecular chlorine and chlorine dioxide as oxidants. The first attempt at this in Canada was at Dryden, ON in 1957. Dryden creatively employed upflow towers, a relatively new design that ensured the pulp stream had adequate backpressure to hold the reagent in solution until exhaustion, before exposure to ambient atmosphere at the top discharger of the tower.

To more fully appreciate what I'm saying here, those of you without first-hand experience with pulp slurries may find it interesting that up to 2% concentration, chemical pulp slurry flows like a typical liquid; at 6% concentration, attempts to pour it result in discrete free-falling soggy blobs; at 15% concentration, it's firmer, and has more load-bearing capacity than some wet fairways I've golfed on.

This CEDED sequence employed 15-20 kg chlorine dioxide /tonne of pulp, requiring more generator capacity, often satisfied by installing a new generation process system of double capacity.

Although upflow towers performed admirably at suppressing the flash-off of chlorine dioxide, they did nothing for in-process surge capacity, something valued in our industry because it contributes to operational reliability. The compromise was the upflow-downflow or J-tube reactor tower that was introduced about 1960. With 20% of its volume in the upflow leg, it suppresses gas-off, but with 80% in the downflow vessel, it allows surging for improved availability.

Historical Evolution of Generation Technology: Part 2

To eliminate the significant acidic liquid stream from first-generation processes, a new generation of generator crystallizer processes emerged, employing sodium chloride reduction chemistry and vacuum crystallization. Erco called their approach R3 and Hooker called theirs the SVP. These systems produced a byproduct molecular chlorine water stream off the absorption system that could be used in the first stage. This significantly reduced the amount of chlorine gas that had to be purchased, by about 30%, but still posed an environmental liability during the early 1990s demand for pulp bleached without the use of chlorine gas to minimize the release of mutagenic dioxins and furans in the process effluent.

The push to this environmentally friendly molecular chlorine-free pulp was straightforward, using chlorine dioxide, but generally in low consistency upflow reaction towers originally designed for chlorine gas. Chlorine dioxide bleaching had always been done at 10-12% fibre concentration up until that time and there was concern that low consistency pulp slurry at 3.5% would be too dilute to accommodate the reaction kinetics. The concern turned out to be unfounded however and in Saint John, NB, in 1990, after several months methodical planning,

we made the plunge one night when our chlorine vaporizer ruptured. We never looked back.

As the capacity of these R3 and SVP systems grew to satisfy the 35 kg chlorine dioxide/tonne of pulp required for ECF or molecular chlorine free bleaching, even having solved the problem of a highly acidic process effluent to neutralize, they still yielded a byproduct sodium-sulphur makeup stream exceeded the sulphur requirements of all but the highest loss pulping and recovery cycles.

The remedy was a further shift to the chemistry yielding the least-sulphur byproduct stream. The Solvay methanol chemistry made a comeback in the vacuum-crystallization generator era. Erco's R8 system and Eka Chemicals', the successor to Hooker, SVP Lite both operate on the basis of the Solvay methanol reduction chemistry. Further process concepts have grown from these for specific applications but the Erco R8 and Eka SVP-Lite process can be considered the mainstream base cases as of 2005.

ClO_2 Storage System Risk Assessment and Control

In 1970, in Dryden, ON, I had the opportunity to lead the operations startup team on a 10 tonne/day mathieson generator system. The storage capacity for solution was 34,000 US gal or 1.3 tonnes. The generator system we now have at Mackenzie, BC, is an Erco R8 rated at 35 tonnes/day capacity. Our storage capacity is 500,000 US gal or almost 20 tonnes. Our mill is relatively small and our chlorine dioxide system is small.

There are numerous systems operational in North America with 60 tonnes per day capacity and storage of 35-40 tonnes. Proper management of the facility, from a process safety management perspective is essential. It's now my pleasure to turn the presentation over to Dr. Ertugrul Alp, who I first met during his due diligence overview of our chlorine dioxide system at Prince Rupert, BC, in 1995.

Inherent Hazards of ClO2

ClO_2 is a yellowish gas with a boiling point of 11 ^{0}C and with a sweet odour similar to chlorine. It is highly toxic. Prolonged exposure desensitizes people, and its odour threshold is on the same order as its toxic limits. Inhalation of ClO_2 at high concentrations can lead to death or serious injury. The IDLH level is 5 ppm in air (IDLH – Immediately Dangerous to Life and Health – represents a maximum level from which one could escape within 30 minutes without suffering any symptoms that could impair escape or any irreversible health effects)(NIOSH, 2000). Its 15-minute STEL-TLV (Short Term Exposure Limit – Threshold Limit Value) is 0.3 ppm. Its 8-hour PEL (permissible Exposure Limit) is 0.1 ppm.

ClO_2 gas is also highly unstable, and may explode on heating, on exposure to sunlight or if subjected to shock or sparks. It is a strong oxidant and reacts violently with combustible and reducing materials, such as organics, phosphorus, potassium hydroxide and sulphur, causing fire and explosion hazards. Its Lower Explosive Limit is around 10% in air (ILO, 1999). At partial pressures above about 120 mm Hg it will decompose spontaneously and explode. At higher pressures the explosions become more violent; at approximately 190 mm Hg explosion relief may be inadequate and rupture of the vessel may occur. These explosions can ignite combustible materials.

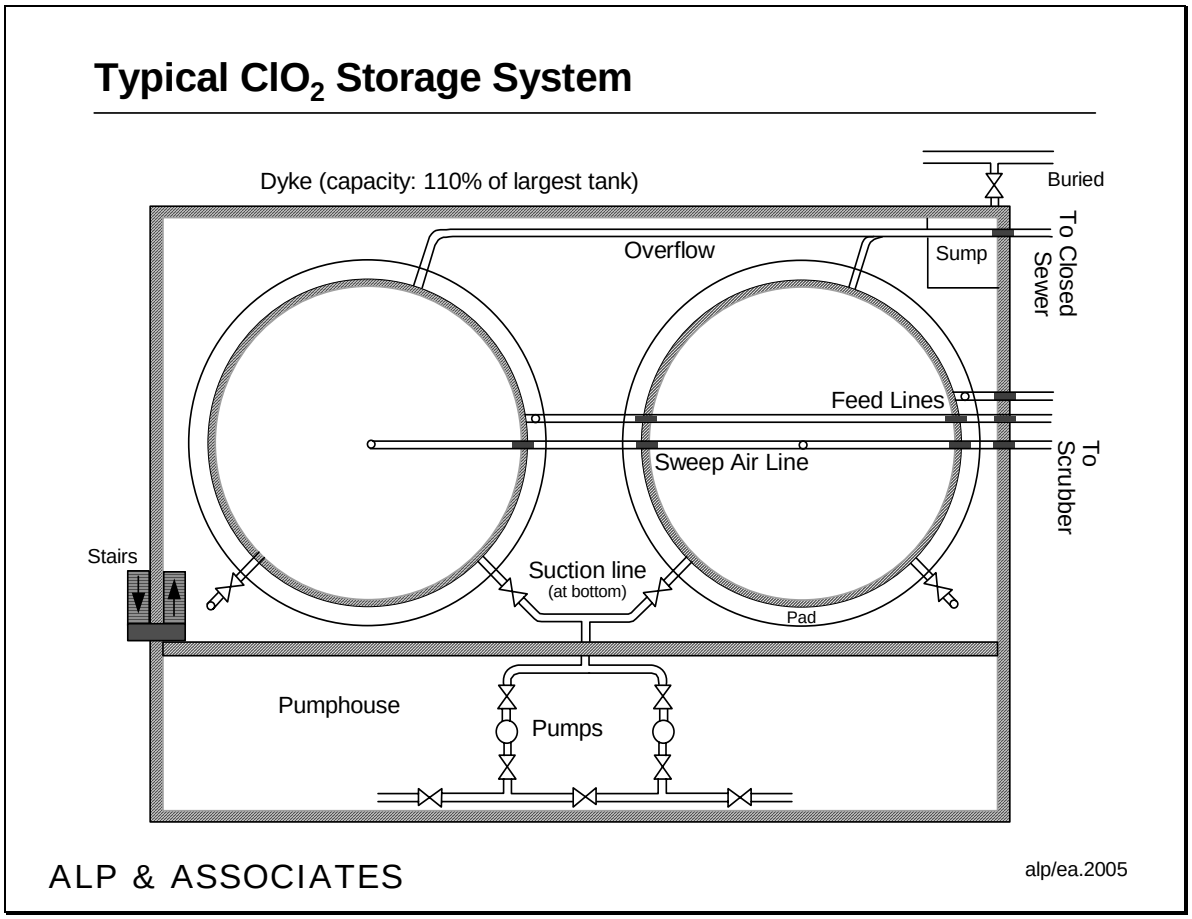
Because it is unstable, ClO_2 gas is generated on-site using one of the processes describer earlier, and stored as a solution in water, typically at concentrations around 7-10 g ClO_2/L of water at 5C to 7C.

In case of a spill of ClO_2 solution from storage or process lines, ClO_2 will start gassing off and form a toxic cloud. The molecular weight of ClO_2 is 67.5. Due to its molecular weight, it is heavier than air, and will tend to result in heavy gas clouds that hug the ground and are relatively difficult to disperse.

System Description

A typical storage system for chlorine dioxide consists of two (or more) cylindrical storage tanks in a containment dyke, along with the associated pumping arrangement, as shown in Figure 1. Tanks are fixed-roof and generally made of FRP (fibreglass reinforced plastic) or are FRP-lined to guard against the corrosive solution. Typical storage volumes are around 400 m^3 (100,000 US gal.) per tank.

Figure 1 A Typical ClO_2 Storage System



The dyke typically has a capacity of 110% of the largest tank within the dyke. It would be equipped with a sump and drain valve with connection to mill acid sewer. Overflow in case of overfilling would also typically be directed to the acid sewer.

Discharge nozzles from the tanks are located close to the ground. The discharge lines meet at a common pump suction header that typically breaches the dyke. The solution is then pumped to the pulp bleaching process area for injection into the pulp slurry stream through mixers ahead of each of the chlorine dioxide reaction towers. The valves on the suction lines are normally kept open, for level equalization during operation.

Feed lines from the ClO_2 absorption towers are connected to the tanks around 1 m from the ground. An air sweep back into the absorption towers is provided to ensure that the concentration of ClO_2 in the vapour space of the tank is kept below its explosive limit. Explosion hatches are provided for protection against small explosions. Vacuum breaks are provided for protection against tank collapse in case or too rapid drawn-down of liquid.

Potential Hazardous Event Scenarios – Process Safety Incidents

The major event scenarios of concern related to a ClO_2 storage system include tank and pipe ruptures. While these are very low frequency events, they have occurred in the industry. Their potential causes include physical impact due to falling material from adjacent process equipment or buildings, overhead conveyor galleries or overhead lifting of heavy equipment; corrosion (of lined tanks); tank collapse due to high vacuum in case of failure of vacuum breaks; tank explosion from build-up of ClO_2 in vapour space due to failure of air sweep; and rupture of pump expansion joints.

Valve and flange leaks, requiring operators to suit up and isolate equipment, can also occur (more frequently).

One notable spill that has occurred in Powell River, BC, in 1994, was the result of bursting of a much-neglected adjacent wooden pulp tank, the debris rupturing two ClO_2 storage tanks, spilling 600 m^3 of ClO_2 solution. Breaches on the dyke wall resulted in release of the solution outside the dyke, spreading to a large area and gassing off, resulting in a large toxic gas cloud. Due to the direction of the wind at the time, there were no casualties; however, MacMillan-Bloedell was fined because they had to divert the spill into the ocean (Malaspina Strait) to minimize the duration of the toxic cloud, resulting in fish kill (1 count under the Fisheries Act, $70,000, and two counts under the Waste Management Act, $30,000). This event resulted in the BC Council of Forest Industries' risk assessment and emergency response planning drive in the latter half of the 1990s, thus improving process safety management practices and emergency preparedness in the BC Pulp and paper industry.

In these risk assessments, an interesting scenario that was found to be common to many mills in BC at that time was the following. It was noted above that the suction lines from adjacent ClO_2 tanks would typically be connected to a common suction header, and the manual valves on these lines would normally be open for operational purposes. In case of a large break anywhere on these suction lines, tank drain nozzles, or on the common header, the solution would rapidly start filling the dyke. The manual valves would need to be accessed by an operator (suited up), who would need to literally swim his or her way to the valves in order to isolate the tanks. Since

during such an emergency, operators would not want to swim in ClO_2 solutions, both tanks would drain through the break, exceeding the capacity of the dyke (110% of the largest tank within the dyke!), overflowing and spreading around the dyke, and start gassing off over a large surface area. We will discuss how such a scenario could be mitigated using simple process safety practices, further below.

Worst Case Scenario Modelling

If a spill is contained within a typical dyke, the surface area available for gassing off will be equivalent to the dyke area minus the tank footprints, assuming that the tank roofs are intact. Such a scenario can be shown to result in hazard distances much smaller than if the release spreads outside the dyke.

For example, for a spill contained in a dyke suitable for three 60,000 US gal, 14 ft diameter tanks, the modelled distances (using the SLAB model, developed by the US Lawrence Livermore Labs) to the IDLH level of 5 ppm were 120 m and 280 m, respectively for D stability (neutral stability atmosphere, mechanical turbulence dominant) 5 m/s winds (medium winds), and F stability (very stable atmosphere, little turbulence) 1.5 m/s winds (low winds).

If spill from all three tanks were allowed to overflow and spread before entering into the nearby mill sewers (clearly this scenario is very site-specific), the modelled distances to 5 ppm were 1.8 km and 8.1 km, respectively for D5 and F1.5 weather conditions.

It is noted that ClO_2 dissociates rapidly upon exposure to solar radiation (sunshine), forming Cl_2 gas (for comparison, chlorine has an IDLH level of 10 ppm, double that of ClO_2). Thus, this natural dissociation will tend to reduce the hazard distances, and assuming no dissociation will result in conservative estimates of hazard zones.

Under strong insolation conditions (bright sunshine at noon in July, southern BC latitudes), the time it would take for ClO_2 to dissociate to about 10% of its initial concentration is around half a minute. At 5 m/s winds, this would imply approximately 150 m of travel, within which most of the ClO_2 would dissociate. At 1.5 m/s (perhaps during low-wind but highly convective and turbulent situations), the travel distance would be about 45 m. Therefore, assumption of complete conversion to Cl_2 under such high insolation conditions would be justifiable.

On the other hand, under clear skies shortly after sunrise in January, the time it would take for ClO_2 to dissociate to about 10% of its initial concentration is around 500 s. This would imply travel distances of 2500 m and 750 m for 5 and 1.5 m/s winds, respectively. Therefore, neglecting dissociation is more reasonable and justifiable.

Under nightime conditions, dissociation of ClO_2 should be neglected.

Risk Control Through Process Safety Management and Emergency Response

A process safety program has many elements. These include (OSHA 29 CFR 1910.119): employee participation, process safety information, process hazard analysis, operating procedures, training, contractors, pre-start safety reviews,

mechanical integrity, work permit, management of change, incident investigation, emergency planning and response, and auditing.

The risks associated with ClO_2 storage systems can be effectively controlled through judicious use of process safety management techniques and appropriate emergency response.

In general, most pulp mills have many of these different elements in place, however, not necessarily in a well-laid out program. The weakest elements are probably process hazard analysis and management of change. Regarding process hazard analysis, although engineering firms who design projects routinely carry out such studies, this information is generally not passed on to the mills, and the mills themselves typically do not carry out such assessments on a periodic basis. This weakness manifests itself in management of change, where not all changes necessarily go through an appropriate level of process hazard analysis, thus potentially jeopardizing future operational integrity of the mill processes.

Returning to more specific issues, a simple process safety measure to mitigate the effects of a suction line break scenario as described above is to add remote controlled valves next to the manual valves on the suction lines of each tank, thus preventing the necessity of an operator “swimming” to the manual valves for isolating the storage tanks. Installing an alarm on high rate of level change, to sound in the control room would also improve response to such an incident. This arrangement became standard in BC mills following the risk assessments conducted in late 1990s. Another arrangement is to install automatic valves and interlock them to a high rate of level change.

Foam systems for dykes, or covering a contained spill with tarp (tarpaulin), would cut down gassing off thus reducing the size of the hazard zone from a ClO_2 cloud from that spill.

Other potential scenarios following large spills of ClO_2 encountered in different mills included spills entering sewers and water treatment systems, gassing off along open drains/ clarifiers/ water treatment ponds (bio-treatment), rendering water treatment inoperative requiring re-stocking of bio-agents, entering nearby buildings (some mills in northern areas have their ClO_2 storage tanks within enclosed buildings in the first place), gassing off within buildings, the gas being carried by natural building drafts into adjacent buildings, and discharged from building vents.

Understanding ahead of time where a spill could go within the complex sewer systems and interconnected buildings in pulp mills would improve emergency response, and minimize damage to environmental systems and minimize potential for gassing off in unexpected locations thus preventing worker exposure. Thinking through ahead of time what to do with the waste in a contained spill will also improve the chances of painless recovery from a spill.

A tank management program, which involves testing and inspection of tank shell thickness, nozzles, instrumentation, and a regular log of this inspection and testing, is important in minimizing chance of large tank breaches due to deterioration. Of course, such a tank management system would be applicable for all critical tanks, and not only ClO_2 tanks.

Some mills have long ClO_2 pipe runs (e.g., over 3000 ft) made of FRP. A typical detection method for pipe rupture is to install flowmeters on each end, measure the differential, and interlock into shutdown in case of a larger-than-expected differential. For start-up purposes, an interlock bypass may become necessary, which should be automatically deactivated after flow stabilization.

Fibreglass ClO_2 piping can experience problems with thermal shrinking and expansion, causing leaks. A rigorous preventive maintenance program is needed to identify and correct such problems in a timely fashion.

Drain valves on ClO_2 tanks are sometimes not locked, and could be inadvertently (or with malicious purpose) opened easily. Installing locks is a simple measure that is not overly restrictive for operational purposes. Another option is to install proxy switches that would alarm if a drain valve is open.

Another common finding is open dyke drain valves, left open after a heavy rain. Procedural controls and daily inspections can help reduce this frequent cause of dyke breaches.

Last, but not least, the author has observed at one mill a heavy lift by a crane over several FRP ClO_2 tanks, even though this overhead zone has been designated as a "no-lift zone". None of the engineering and technical personnel present took the initiative to stop the lift while it was starting. The occurrence was later investigated as a "near-miss", and it was found that the crane operator was told to complete that lift that day "or else", a larger more suitable crane was not available, and furthermore, while he was aware of the toxic nature of ClO_2, he was not aware that a major rupture of any of the tanks resulting from a lift failure could have lead to many fatalities, including possibly in the nearby community.

The fact that this mill had an investigation policy for "near-misses" indicates the relative sophistication of this facility in terms of its process safety management systems. It is also quite clear that the culture of safety was not yet engrained in operating and technical personnel, as evidenced by the occurrence of the lift, and reluctance of the other technical personnel to intervene and stop the lift from taking place.

Closure

The most significant single PSM challenge in the chemical pulping sector of the pulp and paper industry is the chemical recovery boiler. But this risk has been so dramatic and so high profile, that is has been covered by the Black Liquor Recovery Boiler Advisory Committee, http://www.BLRBAC.org for over forty years.

Today, we have been talking about translating the same level of disciplined management to one of the next highest profile risks: chlorine dioxide generation-absorption-storage systems which have made a tremendous evolution over 50-60 years. Similarly, bleaching tower designs have evolved from downflow to upflow to J-tube to some high-intensity upflow. As dosage rates have risen from by a factor of six, 0.5% to 3.0%, and production rates have risen by a factor of eight, from 250 ADt/day to 2000 ADt/day, storage capacities have gone up by a factor of 45-50, just to sustain the same retention time.

Some of our industry's most-publicized environmental emissions, with potential risks to the general public, have been the result of chlorine dioxide discharges from Canadian pulp mills over the past fifteen years.

In spite of the apparent superficial contravention of conventional wisdom regarding minimizing quantities stored, storage of chlorine dioxide solution in the quantities appropriate for competitive operation of kraft pulp mills can be achieved safely through observing basic process safety management discipline.

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Biographical Information:

Ertugrul Alp:

Principal of Alp & Associates Incorporated, Richmond Hill, Ontario, Ertugrul is a mechanical engineer (nuclear option) by training, with an undergraduate degree from the Middle East Technical University in Ankara, Turkey. He received his Ph.D. from the University of Waterloo in 1978. He started his career at Westinghouse Canada, Atomic Power Division, in Hamilton, Ontario, as Manager, Analysis and Modelling. He then joined Concord Environmental (Bovar Environmental after 1994), an environmental consulting company, in 1982, and became one of its principals, serving as Manager, Risk Assessment and Management until 1997. He led the Safety and Risk Practice of Arthur D. Little in this firm's Toronto office in 1997-99, after which time he formed Alp & Associates.

His experience covers a number of industrial sectors, including chemical, energy, pulp and paper, mining, steel, and transportation sectors. Between 2001-2005 he also served as a member of the Board of Directors of Cayeli Bakir Isletmeleri (Cayeli Copper Works), as a representative of Inmet Mining, an international mining

company. He was the chair of MIACC's Risk Assessment Expert Committee between 1994-99, and a member of the CSA Technical Committee that developed the Q850 Risk Management Standard. He was also a participant in the NATO CCMS (Committee for Challenges of Modern Society) Pilot Study on "Disaster Preparedness Planning for Chemical Accidents."

Currently, he is Vice-chair of the CSChE Process Safety Management Division, and a member of the Canadian Advisory Committee for ISO's new international risk management standard, due for publication in 2007.

Thomas Boughner:

General Manager of Pope & Talbot Ltd. in Mackenzie, British Columbia, hails from Charlotteville Township in the heart of the Carolinian Forest Region on Ontario's "South Coast". His qualifications include B. A. Sc. (Chem. Eng.), Waterloo, 1970 and P. Eng. (BC and ON) supporting 35 years of experience in six Canadian kraft pulp operations, coast to coast. In April 1999, he was appointed general manager of the Mackenzie 230,000 tpy bleached chemical market pulp mill with 255 employees and gross annual sales of $200 million.

His career includes assignments as startup team leader, process engineer, production supervisor, superintendent and manager, capital projects manager and general manager. He has worked with mathieson ClO2 systems at Dryden, Marathon, Fort Frances and Prince Rupert; SVP systems at Irving and Prince Rupert and SVP-MeOH/R-8 technology at Irving and Mackenzie. His responsibilities have included operations supervision, process optimization, modernization alternatives selection, process conversion and total site performance accountability.

He is a member of the Pulp and Paper Technical Association of Canada, where he has served on three committees, and also of parallel organizations in USA and Brazil. He has published papers on chlorine dioxide bleaching practices in 1980 and on application of PSM in the pulp and paper industry in 2004. Tom serves on the Chemical Engineering Industrial Advisory Council at UBC, is a member of CSChE, which he currently serves as Process Safety Management Division Chairman and is President of the B. C. Forest Industry Health Research Program.