## Slide 3

* The release of nutrient are well documented to cause:
* Anoxia: low levels of dissolved oxygen
* Harm to aquatic life: ammonia toxicity can effect fish mortality, reproduction and health
* Eutrophication: Excessive growth of algae reducing dissolved oxygen
* Regulations in Canada have been slow
* 2012 mandatory secondary treatment
* Primary removal of large solids
* Secondary treatments are biological processes to removal organic material
* Tertiary treatments include biological nutrient removal and disinfection processes
* Nutrient being nitrogen and phosphorous compounds
* Only 17% of Canadian wastewater treatment include tertiary treatment
* 1 in 4 facilities need to be upgraded

## Slide 4

* Conventional wastewater treatment relies on large concrete tanks
* The concrete is expensive as well as excavation costs
* Their rectangular cross-section, as illustrated in the comprised fluid dynamic model, provide poor mixing conditions
* The kinetic energy fields show regions of stagnation in dark regions (1,00 time lower energy from bulk)
* Large energy requirements mainly due to aeration
* They are difficult to upgrade due to their size and their expense to build

## Slide 5

* The STAR vertical bioreactor has three distinct stages
* The stages include two anoxic stages followed by an aerobic stage
* Anoxic : no dissolved oxygen present but other oxygen compounds present
* Biological nutrient removal bioreactor
* It exhibits a vertical orientation with a circular cross section to reduce the foot print of the reactor and enhance mixing
* Fluid travels by gravity from one stage to the next without the assistance of additional pumping
* The design is modular which enables an easy upgrade path with additional reactors
* They are constructed with PVC which is a cheap and strong material
* The technology was developed by Dr Reza and Dr Alvarez Cuenca

## Slide 6

* The experiment include two recycle streams, the sludge and internal recycle
* High level of recycle which were accounted for
* Experiment was run with tap water rather than wastewater
* NaCl was selected as a tracer, LiCl can be used for waste water
* Tracer was injected in the feed stream

## Slide 7

* Instrumentation included 4 new conductivity sensors
* They were placed at the exit of each stage of the reactor
* 50 mL of saturated NaCl solution was used
* The sensors were connected to the current DAS which was connected to a Pc with LabVIEW

## Slide 8

* Picture of the main reactor body
* Picture of the 50 mL syringe for injector

## Slide 9

* RTD studies the mixing behaviour of a fluid flow
* Was first introduced by Dankwerts in 1952
* Conductivity of the tracer was found to be linear with concentration
* Since the RTD functions are normalized, can use an arbitrary measure
* A pulse signal was selected as it is easier to generate and requires less tracer

## Slide 10

* First RTD function is the probability density function
* Represents the probability of a tracer element leaving the reactor a at time t
* Derived from normalizing the concentration curve by its integral
* The integral was found with numerical integration
* E curve represent a system response to a pulse signal

## Slide 11

* Moments are a set of equations that describe a distribution
* Used to compare them
* The first moment represents the mean, it is used to determine the sample mean time
* The second moment in the variance which represents the spread
* The first moment can be used to transform the RTD curves to dimensionless time theta
* The shape of the curve stays the same

## Slide 12

* The E curve can now be compared to different models
* Models are constructed and solved for a non-reactive tracer concentration
* This concentration function is then converted to the probability density function from previous equation
* The E(t) or E (theta) can be compared to the experiment RTD to find a fit
* The theta simplifies as it removes the parameter of tau in the function
* The ideal CSTR and PFR were compared
* Used the RSME
* Real reactors represents deviations from these conditions
* Don’t have to make physical sense
* An example is the cstr in series model which behaviour goes from an ideal CSTR to Ideal PFR as the number of cstrs goes from 1 to infinity
* Represents systems between ideal conditions

## Slide 13

* Recorded data is in blue
* First graph shows the ideal reactors
* Between the ideal models, the cstr in red better describes the RTD
* Many real reactors were tested with the generalized cstr in series being a good fit
* Generalized replaces a factorial for the gamma function to represent number of cstrs as real numbers rather than natural numbers
* Ex .75 or 2.25
* Increased model parameters create more complicated models that may be describes the RTD

## Slide 14

* The second RTD is the Distribution function F (T)
* represents the cumulative some of tracer exiting the reactor
* is related to the probability density function
* can be expressed dimensionless
* represents the step change response
* can be used to calculate the hold back, the portion of tracer that spends more than average amount of time in the reactor
* the integral of the distribution function till theta =1
* the segregation can also be determined, which is the deviation from the CSTR holdback

## Slide 15

* The holdback is shown with a value of 0.2365 vs the ideal CSTR of e^-1 which is about 0.3679
* The segration represents the deviation from an ideal cstr so the value is negative and is the difference between the holdback of the reactor and the ideal cstr

## Slide 16

* Effects of Dead space and by-passing can be observed by compare the MRT with the sampling mean time
* Ideal condition they are the same
* If the sample is less than there is dead space, if it is larger than there is dead space
* Represents overall systems, may have different regional values
* By running an experiment with both recycles turned off, a by-passing rate of 7.5% was found

## Slide 16

* Conclusion, the RTD curve for the STAR vertical bioreactor were found
* The IDEAL CSTR and generalized CSTR in series were found to be good fits
* A high level of mixing was observed with a segregation value of -0.16
* Future work to include combining with kinetic models
* Optimization of the MRT by controlling the internal recycle rate
* The creation of a CFD to determine local regions of by-passing and dead space
* Expansion of the unit capacity