

## **Collaborative Research and Development (CRD) Grant Final Report**

**Due date:** (December 1, 2008)

### **Is your personal information correct?**

**Yes**

**No** (please make the necessary corrections)

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### **Is the project information below correct?**

**Yes**

**No** (please make the necessary corrections)

**Project Title:** Catalytic combustion for the elimination of methane, BTEX and other VOC

**File Number:** CRDPJ 325997 - 05

#### **Co-investigators(s):**

S.E. Wanke, Chemical and Materials Engineering, Alberta

#### **Collaborator(s):**

#### **Supporting Organization(s):**

W. Hillier, Husky Oil Operations Ltd  
T. Such, Petroleum Technology Alliance Canada  
B. Peachey, New Paradigm Engineering Ltd  
P. Howie, Scott-Can Industries Ltd

## **1. Progress Towards Objectives/Milestones**

- 1.1 To what extent were the objectives of the CRD project achieved? Please rate your answer on a scale from 1 to 7, where 1 means not at all, the mid-point means somewhat, and 7 means to a great extent.

Place your rating of 1 to 7 here: \_\_6\_\_

## 1.2 Please provide in the box below:

- a brief description of the overall objectives of the research project as awarded;
- a description of the progress made towards these objectives as a result of the grant;
- a description and justification for any deviations from the original objectives;
- a description of the scientific and/or engineering significance of the results; and
- a brief discussion of the potential benefits to Canada.

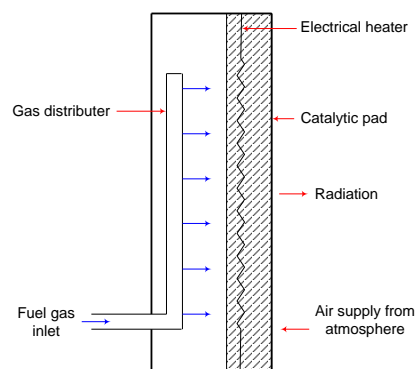
**1. Introduction and scope**

This project was part of an initiative to address methane and VOC vent emissions in upstream oil and gas operations that are currently considered to be uneconomic and technically difficult or impossible to reduce by other means. The overall objective was to develop and prove concepts for reactor technologies to enable economical mitigation of these emissions from various sources, including small isolated and fugitive sources. This research deals with solutions of concentrated methane that contain higher hydrocarbons, both BTEX (benzene, toluene, ethylbenzene and xylene) and non-BTEX organic compounds. Typical sources include glycol dehydrators and tank vents. For these vent streams, catalytic combustion is a viable mitigation option, where a suitable catalytic reactor is used to destroy the hydrocarbons. We consider the counter flow diffusive radiant heater as a viable reactor choice.

**2. The counter diffusive catalytic reactor**

In the diffusive radiant heater, the catalyst is supported on a porous fibre "pad". A concentrated fuel stream is fed to the back of the pad, while the combustion air diffuses from the front in counter flow. The intent is to have a very simple converter unit for concentrated vent hydrocarbon streams at an extremely low cost.

Although the prime directive is the destruction of hydrocarbons, including BTEX, these reactors could also supply supplemental heat for process streams, building heat, power generation, cooling or other applications, which would significantly enhance the economics of the units.



The work focused in three main areas. These were:

- (1) Experiments in a commercial small scale counter-diffusive reactor;
- (2) Relative activity tests in a micro-reactor, and to test new catalyst formulations,
- (3) Modelling in 2D and 3D to investigate reactor performance and to understand the experiments.

**3. Results and Discussion, Commercial Unit**

A commercial heater unit measuring 1 ft square was installed in the lab. A series of thermocouples was added to measure and record the temperatures. Effluent concentrations were measured at the front of the pad in various locations using grab samples, which were fed to the GC for analysis. In order to measure the average effluent composition a funnelling hood installed over the reactor (see figure at right). Samples were taken from a sampling port in the top duct. To study the effect of oxygen mass transfer through the natural convection boundary layer that forms at the pad face, a variable speed fan was also installed on top of the funnelling hood to increase the convective oxygen flow in front of the catalytic pad. Other hydrocarbons and water were introduced as required using separate pumps, with injection made through a separate port in the back of the reactor (reactor inlet).



Under normal operation, it was observed that the bottom of the catalyst was hottest, with the temperature diminishing towards the top. The temperature is lowest near the system boundary, where convection losses to the atmosphere occur. The pad had a hot spot near the lower right hand corner on the above figure, which corresponds to the location of the feed pipe. The arrow shows the location of the feed pipe. The heater was successively rotated so that the feed was from each side, the top and the bottom, as denoted by the arrows in the figures below. In each case, the heater was observed to be hotter at the bottom of the pad (as shown in the figures below). It is speculated that the effect may be caused by the natural convection boundary layer at the front of the pad, through which the oxygen must diffuse.

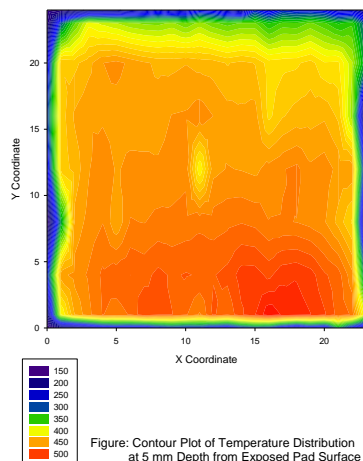
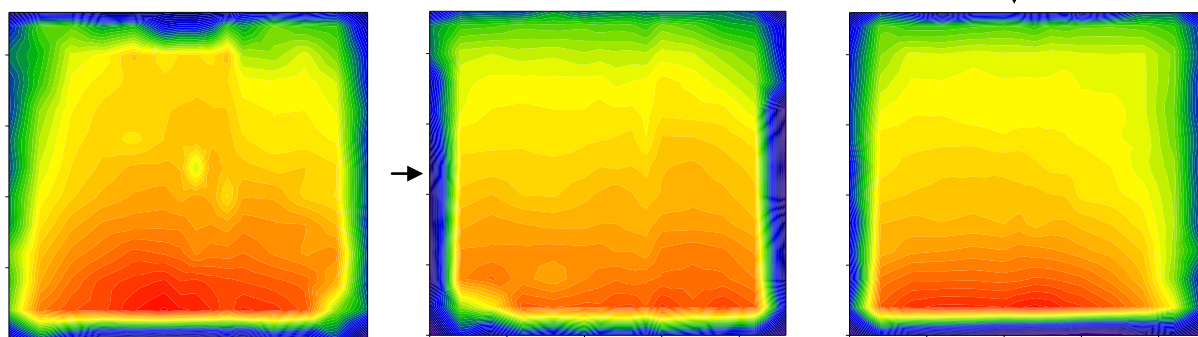
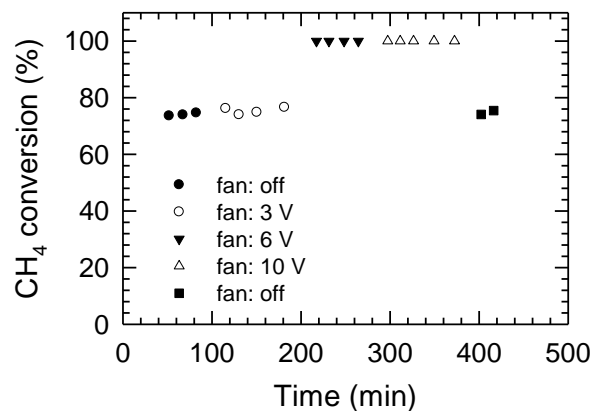
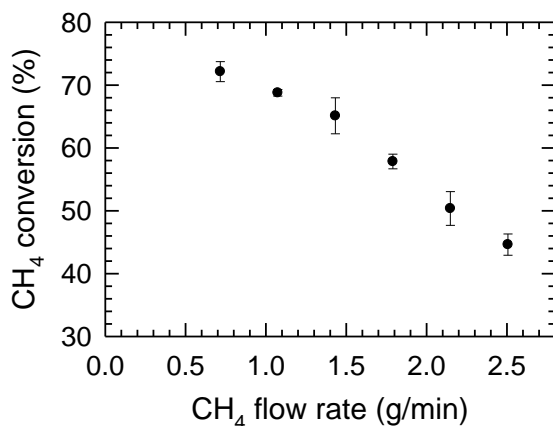


Figure: Contour Plot of Temperature Distribution at 5 mm Depth from Exposed Pad Surface



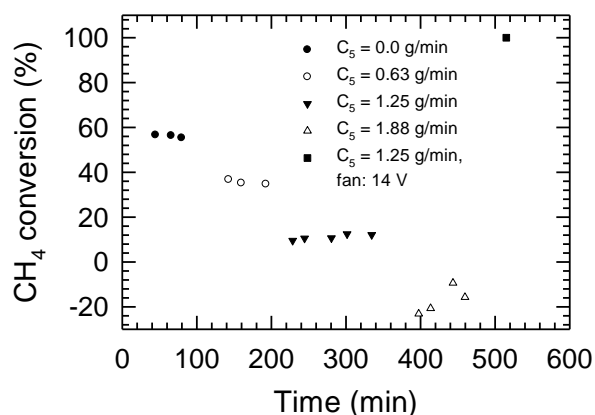
The fractional conversion under normal operation was observed to be less than one, that is, passage of methane was observed. The methane conversion as a function of flow rate is shown below left, while the effect of increasing the flow across the pad face by running the fan in the hood, and hence increasing the oxygen transfer, is shown below right. We see that the fractional conversion of methane decreases as the flow rate increases, although the amount of methane combusted increases. The key result is that increasing the air flow rate across the pad face increases combustion efficiency dramatically. These results strongly indicated that the oxygen mass transfer was the rate limiting step in the reactor operation



Both the temperature measurements and the fuel slippage experiments indicate that the rate limiting step for the reactor operation is the rate of mass transfer of oxygen through the boundary layer that is established at the front of the pad (reactor outlet). This is a significant finding, and differs from the common assumption that the rate limiting step is the diffusion of oxygen within the catalyst pad. It implies that the control of the degree of combustion is easier to achieve than heretofore assumed.

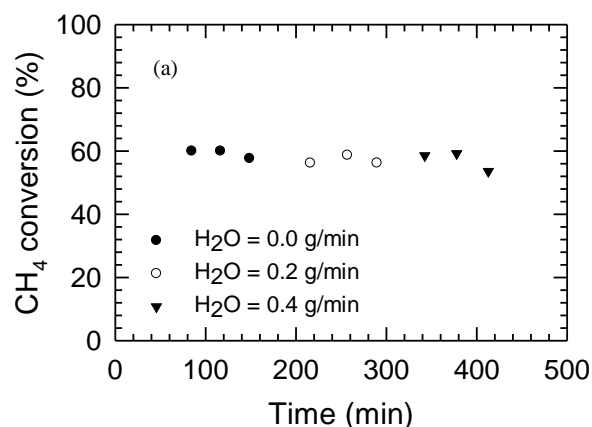
The next series of tests include the addition of other hydrocarbons. The typical glycol dehydrator effluent includes both BTEX compounds and other higher hydrocarbons. In these experiments, toluene was used to represent the BTEX and pentane was used to represent the other non-BTEX non-methane hydrocarbons. The next set of results was obtained by adding in increasing amounts liquid pentane. The methane flow rate was 1.8 g/min. The figure shows the methane conversion as a function of pentane injection rate. It was observed that as the flow rate of pentane increases, the conversion of methane decreases. This observation is consistent with the earlier one of decreasing methane conversion with increasing flow rate. In this experiment, we are effectively increasing the total oxygen demand (because the flow rate of methane was held constant), thus a decrease in methane conversion is expected.

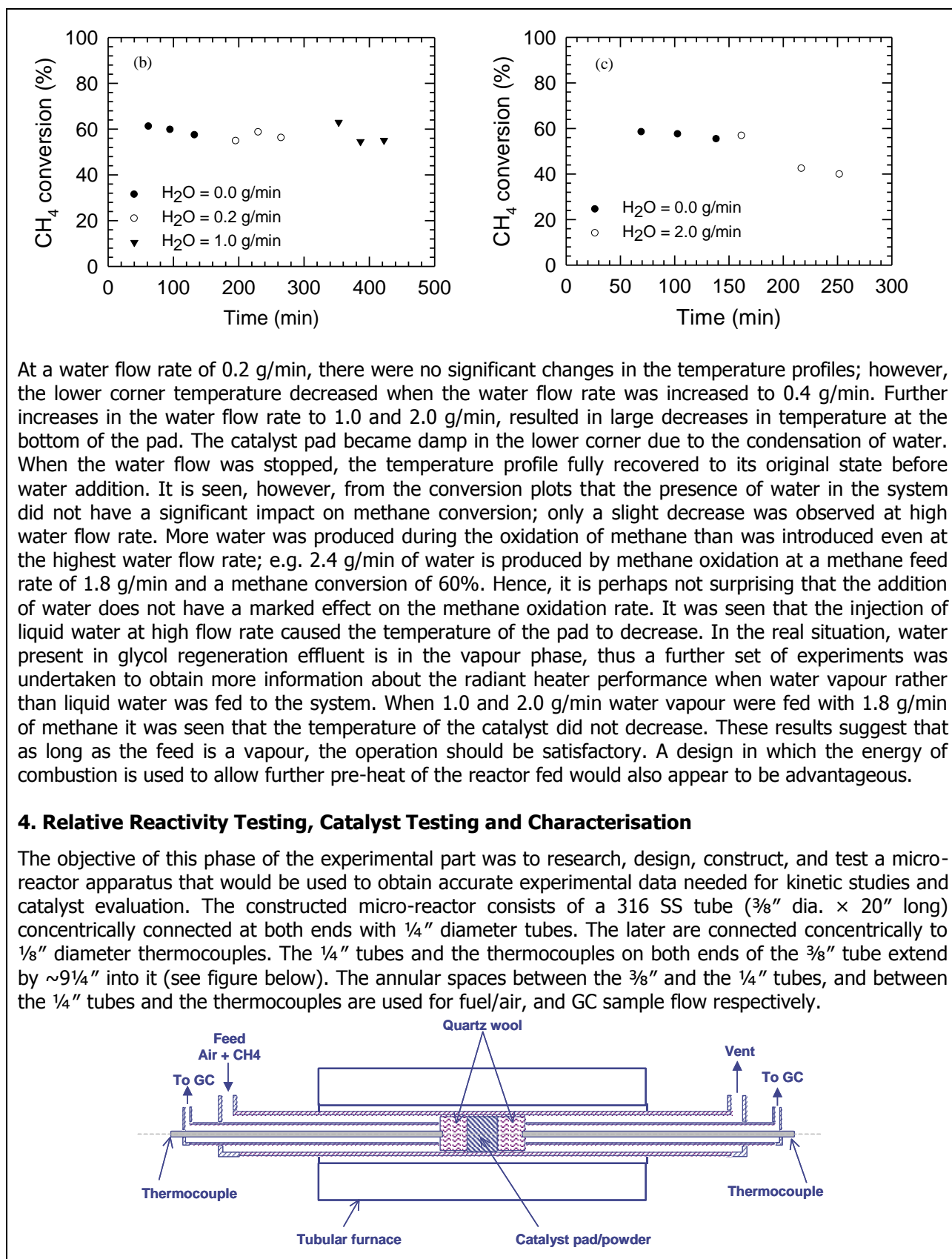
What is more significant, is that there was essentially zero pentane detected in the reactor effluent until the pentane injection rate reached 1.88 g/min. At this point, the calculated methane conversion is negative, indicating that the pentane is not being completely combusted (which is assumed in the computation of methane conversion), which is confirmed by the presence of pentane in the effluent. The major result of this experiment is that pentane is preferentially combusted, compared to methane. When at pentane flow rate of 1.25 g/min, fan was turned on it can be seen from the figure that complete conversion of methane is achieved.



When both pentane and toluene were added to the reactor, the same general trends were observed as with pentane alone. That is, increasing the supply of NMHC resulted in a reduction of methane conversion, and the NMHC are preferentially combusted. A further result of interest is obtained as the liquid injection rate was increased further than were reported in the preceding. At a total liquid injection of 2.8 g/min pentane and toluene with 1.8 g/min methane, the bottom of the catalyst pad was observed to start to cool down. The lower corner temperature drops quickly after C<sub>5</sub> and C<sub>7</sub> was added to the reactor feed.

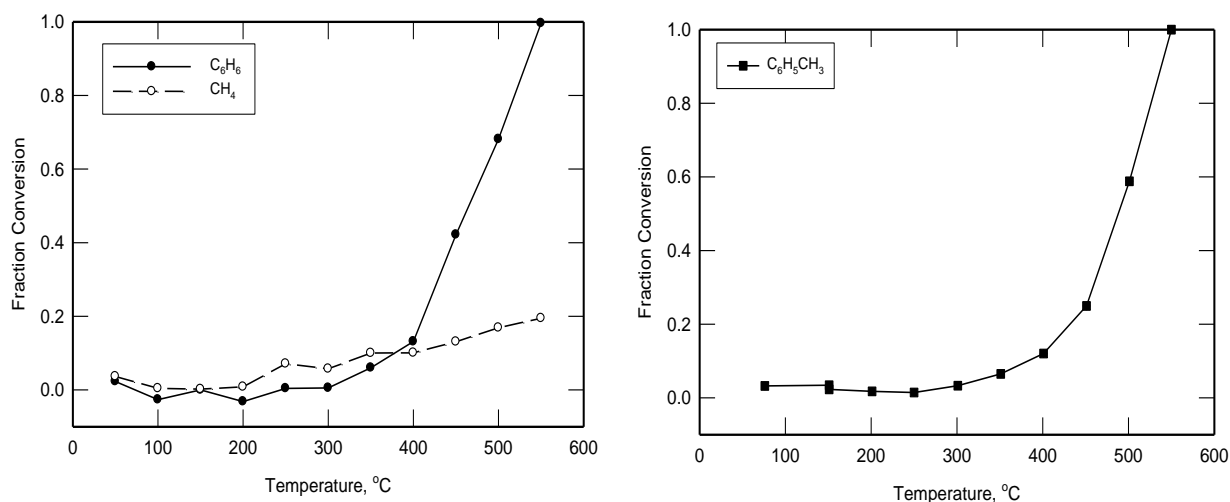
A typical dehydrator effluent contains approximately 40 % by volume water, which is somewhat less than half as much again as is produced by the complete conversion of the other hydrocarbons in the mixture. To investigate the efficiency of radiant heater to combust such a mixture, the effect of addition of only liquid water was studied first, by continuously flowing different flow rates of water into the radiant heater at a methane feed rate of 1.8 g/min. Prior to the addition of water, enough time was allowed for the radiant heater to reach steady-state. The water flow rate was increased in a stepwise manner.





The reactor can be operated in ordinary mode with pre-mixed feed (as shown in the diagram) or it can be operated in counter diffusive mode, where the air and methane are admitted from opposite ends of the reactor. The reactor is heated by a tubular furnace (1¼" dia. × 12" heated length). Four pieces of ceramic half-cylinders suspend the reactor concentric to the furnace. The reactor is connected to gas supply and liquids evaporation system. The reactor design allows for co-feeding premixed fuel/air stream or the two streams can separately be fed from opposite ends of the reactor similar to radiant heaters. The reactor system was tested successfully for a combined on stream time of 50 h. All experimental data are logged on a PC, and the reactor is controlled using a Labview module.

One of the first tasks to perform once the reactor was debugged and calibrated was to examine the relative reactivity of several commercial catalysts and to compare the rates of destruction of methane and BTEX. In these sets of experiments we are only interested in comparative activity, because we know that in the commercial heater we can achieve excellent conversion of methane. A number of commercial catalysts, including both platinum and palladium were tested. Methane, air and BTEX were injected into the reactor. The conversion of each was monitored. In all cases the trends in conversion were the same. We show two typical results here; the conversion over a commercial Pt catalyst for a given set of reaction conditions. The first graph compares the activity of methane and benzene, and the second graph shows the activity of toluene. These results are consistent with the commercial heater results.



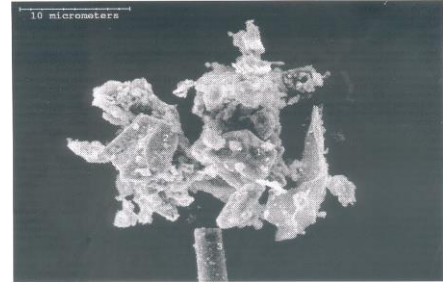
Following this reactivity testing, we have studied a number of potential catalysts for the oxidation of methane. This aspect of the study focused on Pd catalysts. We have studied a commercial catalyst developed by Umicore for methane combustion. We have begun a detailed study of this catalyst, which will be completed over the coming year. So far, we have determined the structure sensitivity of the catalyst for methane oxidation, and shown its potential for the application here. This study will include surface science studies, to correlate the structure effects with the activity.

We have also examined several commercial pads from different suppliers using a variety of techniques, including BET surface area analysis, SEM (Scanning Electron Microscopy), XRD (X-ray diffraction) and neutron activation analysis. We have observed that there is a fairly large variation of properties among the different commercial pads. For example, the fibre support can be either crystalline or amorphous. In some cases, the catalyst is placed on the fibre





network as small particles, whereas in other cases the catalyst is impregnated directly into the fibres. The effective catalytic surface area also has considerable variation, as does the precious metal loading. These properties will be related to the relative activities during this year. The pictures show two representative electron micrographs of a sample catalyst. The picture on the top shows the fibre network and the figure on the bottom shows a catalyst particle.

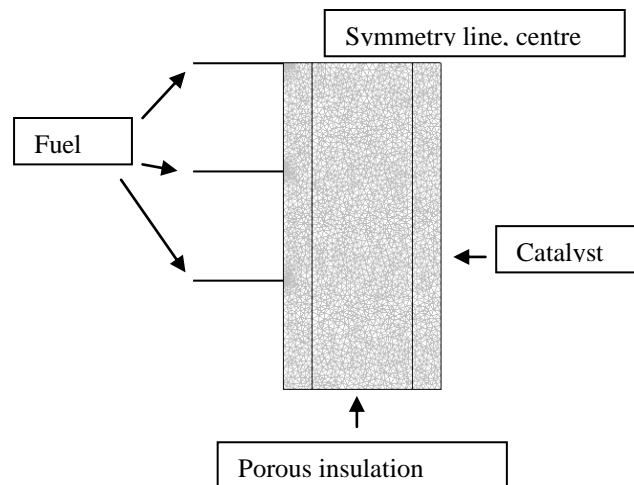


### 5. Modelling the Reactor

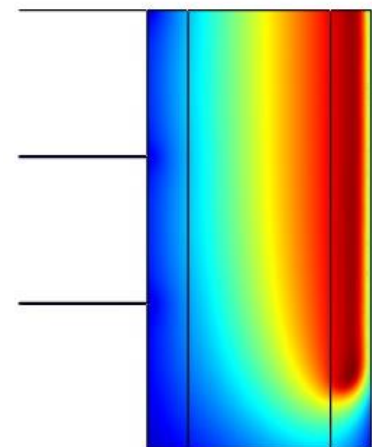
#### *Computer model for the system (two dimensions)*

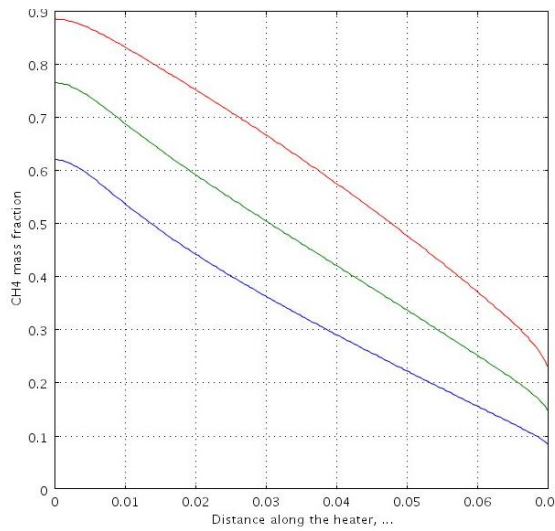
Many design and operational scenarios can be investigated using a properly validated computer model. The model is based on the solution of the governing conservation equations. These equations are solved using the finite element method. The species balances, energy balance and momentum balance equations are solved with the appropriate boundary conditions. For flow in the porous catalyst pad, we use the volume average Navier-Stokes equation.

In the first instance we have built a two dimensional model of the heater. The model domain represents a cross sectional slice taken through the centre of the system. Further, we have assumed symmetry about the mid-plane, thus we consider only a half height of the system. Fuel is fed at the back through long narrow slots. This method is required to impose correctly the boundary conditions on the 2D system. The finite element software package COMSOL Multiphysics is used to solve the equations. A picture of the model domain is shown on the right, with the finite element mesh used.

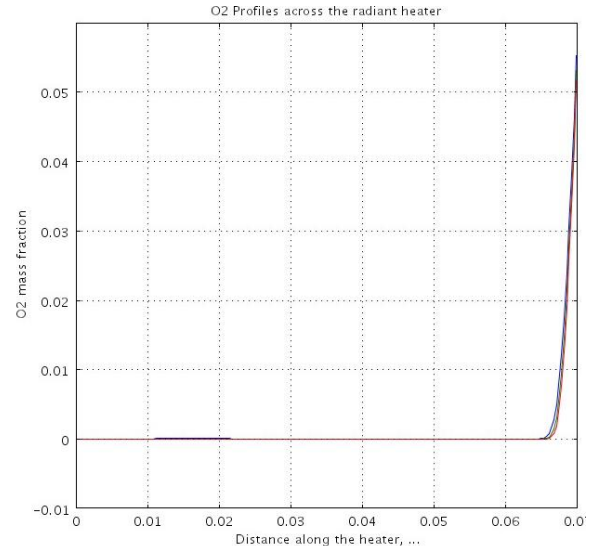


We have used the model as an aid in understanding the performance of the heater. The figure on the right shows a typical temperature distribution in the unit. The maximum temperature occurs near the interface of the catalyst pad and the insulating blanket. The concentration profiles are the most difficult to determine analytically. The figures following show the mass fraction of methane and oxygen as a function of distance from the back of the heater to the front. The profiles are shown along the centreline. Three curves are presented. These represent the profiles at different volumetric flow rates of fuel. It is clearly noticeable how quickly the oxygen is depleted. The limiting parameter in the operation of these units is the rate of oxygen diffusion from the air into the pad. As the fuel flow rate increases, the oxygen is depleted more rapidly, and the concentration of methane at the exterior surface of the pad rise. Any value of methane concentration above zero implies slippage





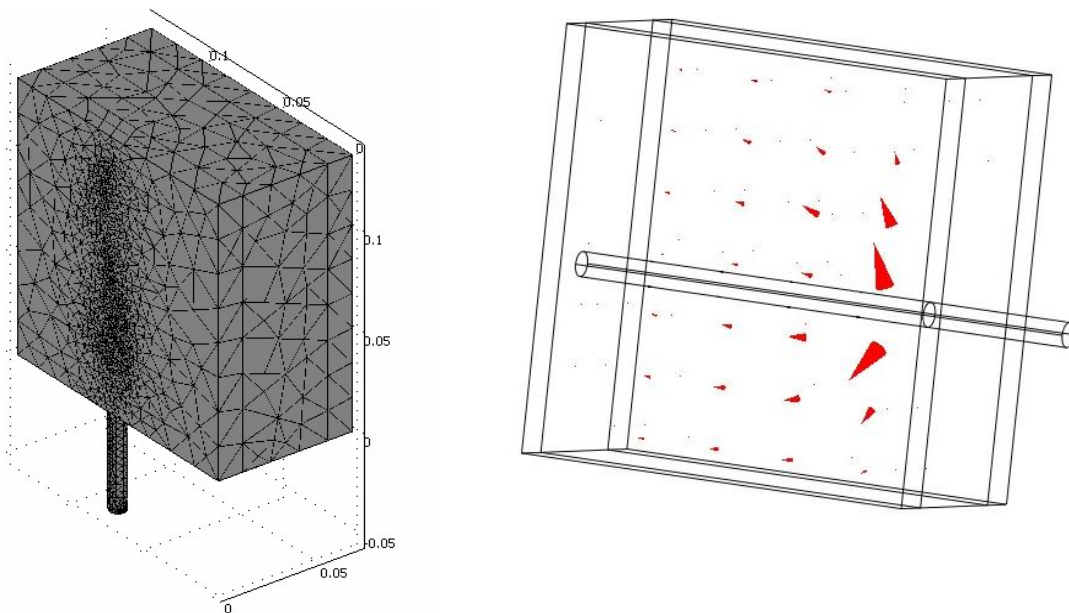
Mass fraction of methane along the centreline from the back to the front at three flowrates.



Mass fraction of oxygen along the centreline from the back to the front at three flowrates.

*Computer model for the system (three dimensions)*

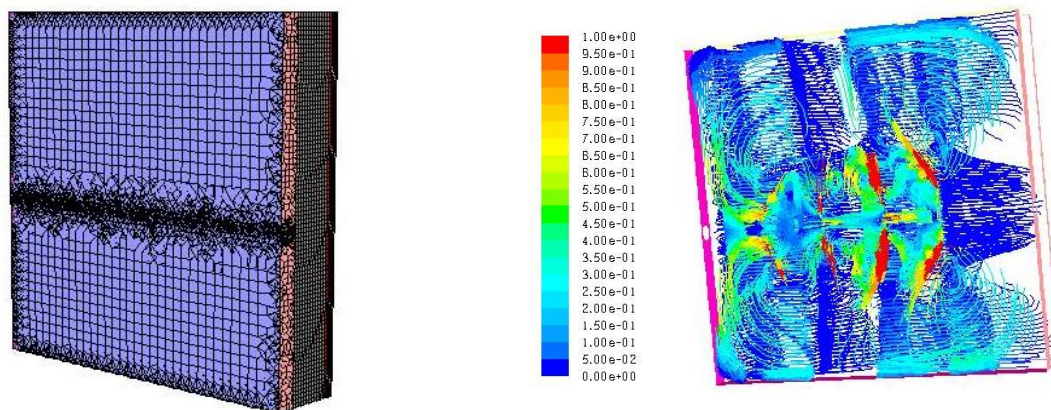
After finishing the two dimensional model, a three dimensional model was built. Preliminary work on the three dimensional model was also performed using the commercial finite element modelling package COMSOL Multiphysics. We started by building a one quarter size model of the system. The mesh is shown below, left.



We ran first the velocity only (momentum balance equation). The feed pipe at the back of the heater contains a regularly spaced series of holes for the feed gas to be distributed. The simulations showed that in fact most of the feed came out of the first set of holes, as shown by the velocity vectors in the figure



above right. Overall, the conclusion at this point is that the fuel distributor can be replaced by a simple open ended pipe. This proposal has been tested experimentally and shown not to make a noticeable difference in performance. During the execution of the problem it became apparent that the COMSOL software package was not the best solution for the modelling software, because it consumes too much execution time. We have switched to Fluent (a finite volume CFD package) and rebuilt the model. Fluent posed its own, and different, set of challenges for implementation, however these have been successfully resolved. The full size unit has been coded and modelled for the flow distribution, and the result is shown below. On the right is the mesh, and on the left is the velocity flow pattern. The trend is the same as for the quarter size unit modelled using COMSOL.



The next step was to implement the full reaction and temperature balance model. This step has been completed, and the execution time is reasonable. There remains some modelling work to be done in terms of validation and then using the model as a tool to understand better the boundary layer effects.

## 6. Conclusions

This study has focused on the use of the counter-diffusive radiant heater as a tool for the destruction of BTEX emissions from a natural gas dehydrator. Based on the observations made, it can be concluded that the technology offers promise for this application. The primary limiting factor in the complete conversion of the hydrocarbon reactants is the transport of oxygen through the boundary layer at the catalyst pad face. Non-methane hydrocarbons are found to be preferentially combusted, compared to methane. Addition of water to the radiant heater did not affect the methane conversion; however, at higher water feed rates liquid water wetted the bottom of the catalyst pad. Introduction of water in the vapour phase eliminated this problem. In all cases, increasing the rate of oxygen transfer to the pad surface, via an induced forced convection boundary layer, enhanced the combustion, and in most cases was able to achieve complete conversion. On the basis of our results we conclude that the use of counter-diffusive radiant heaters, with some forced convection capabilities, is a feasible and economic option for treatment of glycol dehydrator effluent; not only can hazardous compounds be oxidized effectively but the thermal energy generated during the combustion can be recovered and used for other applications.

## 7. Benefits to Canada

The destruction in an environmentally friendly manner of VOC streams from the gas processing industry provides obvious health benefits to Canadians. Reduction of a source of GHG emissions enhances our ability to meet targets set under climate change initiatives.

## 2. Research Team

Please provide an overview of the participation in, and scientific contributions to, the project and for each member of the research team (principal investigator, co-investigators, collaborators, company and government scientists, research associates, postdocs, students, etc.).

The following list describes the research team that has worked on the project since it started.

### **Principal and co-investigators:**

R.E. Hayes and S. E. Wanke

The two co-investigators oversee the project and jointly supervise the personnel. REH has expertise in modelling and catalytic combustion, whilst SEW has expertise in catalysis.

### **Research Associates:**

Joseph Mmbaga, Benlin Liu and Long Wu

Both Dr. Liu and Dr. Mmbaga have contributed mainly to the computational aspects of the project, including code development and tuning. Dr. Liu left in October 2005 to pursue a career in industry. At that time, Dr. Mmbaga joined the project. His primary role is to assist in the modelling endeavours. After the departure of PDF Tariq Mannan (see below) Long Wu joined the project to assist in experimental aspects.

### **Postdoctoral Fellows**

Hassan Hammawa (2005) and Tariq Mannan (2006-2007).

Both of these PDF worked on experimental aspects of the project. Initially HH was the primary PDF. After his departure TM assumed responsibility for this aspect. He primarily worked on the experimental aspects of the project. He left in 2007 for a job in industry.

### **Graduate Students**

Attreyee Basu, Naeimeh Jodeiri, Rajab Litto, Teng-Wang Nien, Adrian Fuxman, Stephen Salomons, PhD students; Hemant More, Gangyu Huang, MSc students; Robert Peffer, visiting Graduate student.

The primary PhD students on the project were Attreyee Basu and Naeimeh Jodeiri. Attreyee Basu worked on modelling and experimental aspects until August 2005, when she departed. Naeimeh joined the project in January 2006. Her work was briefly interrupted by a period of maternity leave in 2006. She has done some modelling work, and did the bulk of the experiments on the commercial counter diffusive reactor. In addition to these two students whose primary project relates to the heaters, several other students were involved in more minor ways. Adrian Fuxman assisted in the development of COMSOL models. Rajab Litto did a study of kinetics on palladium based catalysts to develop activity data for comparison purposes. Stephan Salomons assisted with the experimental aspect of this work, and Teng-Wang Nien developed some optimization methodology for fitting rate equations. Hemant More did a study on three dimensional modelling with COMSOL as part of project to optimize the 3D solvers in COMSOL. In September 2007, Guangyu Huang, from Zhejiang University, China joined the group as an MSc candidate. He has worked on catalyst development, including activity studies in the microreactor. A visiting MSc student from the University of Eindhoven, Robert Peffer, spent three months in the group studying the 3D solver methodology in COMSOL Multiphysics software package.

### **Undergraduate Student**

Pierre Lauthier worked for four months on the project investigating the use and limitations of using the Volume Averaged Navier Stokes equation (VANS) for combined porous media and regular flows, with emphasis on the interface boundary conditions.

**3. Training**

3.1 Please list **each** trainee (Undergraduate Students, Master’s Students, Doctoral Students, Postdoctoral Fellows, Research Associates, Technicians ...) on a separate line in the table below providing: a) the number of years they have been on the project, b) the percentage (%) of time each type of trainee spent on this project, and c) the percentage (%) of funding from this grant (NSERC and industry contribution). If a trainee is fully paid from other sources, type in 0 in the “% of funding from this grant” column. Insert additional rows if necessary. (DO NOT INCLUDE FAMILY NAMES.)

<b>Specify type of trainee (e.g. M.Sc., Ph.D. etc) (one trainee per line)</b>	<b>(a) Number of calendar years on the project</b>	<b>(b) % of research time spent on this project</b>	<b>(c) % of salary from this grant</b>
Undergraduate student	0.33	100 %	100 %
Master student	0.33	25 %	25 %
Master student	0.33	100 %	0 %
Master student	1	100 %	100 %
Doctoral student	0.5	100 %	75 %
Doctoral student	0.25	25 %	25 %
Doctoral student	3	100 %	90 %
Doctoral student	0.13	.25 %	10 %
Doctoral student	0.13	.25 %	10 %
Doctoral student	0.13	.25 %	10 %
Postdoctoral fellow	2	100 %	100 %
Postdoctoral fellow	1	100 %	100 %
Research Associate	0.5	50 %	20 %
Research Associate	2	50 %	50 %
Research Associate	1	50 %	0 %

3.2 What type(s) of interactions did the highly qualified personnel (HQP) have with the partners during the project? (Select all that apply.)

- HQP presented research results to the partners
- HQP discussed the project directly with partners to obtain input
- Partners jointly supervised thesis projects of HQP
- HQP worked regularly in the partner’s facilities
- HQP did not interact with the partners
- Other (Specify): \_\_\_\_\_

3.3 To the best of your knowledge, please complete the following table on the employment of HQP involved in the project.

Type of HQP	# hired by partner	# of hired by industry	# hired by government labs	# employed in academia		# hired by other (specify)	# in academic training
				Faculty	Non-faculty		
Undergraduate Students							1
Master's Students		1					3
Doctoral Students		1					3
Postdoctoral Fellows		1			1		
Research Associates		1		1	1		
Technicians							
Other (Specify)							

#### 4. Dissemination of Research Results and Knowledge and/or Technology Transfer

4.1 Publications, conference presentations, etc.

Please provide the **number** of publications, conference presentations, and workshops arising from the research project supported by the grant in the table below.

Status	Number of publications, presentations...		
	Refereed Journal Articles	Conference Presentations/ Poster	Other (including Technical Reports, Non-Refereed Articles, etc.)
Accepted/Published	1	12	3
Submitted			

4.2 Please provide the bibliographical reference data for the above publications, conference presentations and workshops under the corresponding headings. For publications, specify whether submitted, accepted or published.

##### Refereed Journal Articles:

N. Jodeiri, L. Wu, J. Mmbaga, R.E. Hayes, S.E. Wanke, Catalytic Combustion of VOC in a Counter-diffusive Reactor, *Catalysis Today*, accepted November, 2008.

The current plan for additional publications should result in three more journal papers. These will be (1) a paper devoted to model development and issues. (2) A paper where we use the model as a diagnostic tool to validate our experimental hypotheses and (3) a paper based on the kinetic investigations of Gangyu Huang, incorporating the work of Litto (based on the Umicore Pd catalyst). None of these papers is submitted yet, although (1) and (3) are in preparation.

**Conference Presentation/Poster:**

R.E. Hayes and S.E. Wanke, Catalytic combustion for the elimination of methane, BTEX and other VOC, Air Issues Forum and Poster Session for the Upstream Oil and Gas Industry, Calgary September 22, 2008. (oral)
R.E. Hayes, N. Jodeiri, L. Wu, J. Mmbaga and S.E. Wanke, Catalytic combustion of VOC in a counter-diffusive reactor, <i>7<sup>th</sup> International Workshop on Catalytic Combustion</i> , Zurich, Oct. 2008 (oral)
N. Jodieri, L. Wu, J. Mmbaga, S.E. Wanke and R.E. Hayes, Combustion of VOC in Counter-Diffusive Catalytic Radiant Heaters, <i>20<sup>th</sup> Canadian Symposium on Catalysis</i> , Kingston, June 2008.(oral)
N. Jodeiri, J. Mmbaga, R.E. Hayes, T.M. Mannan and S.E. Wanke, Modelling catalytic radiant heaters for combustion of fugitive VOC, <i>55th Canadian Chemical Engineering Conference</i> , Edmonton, Oct. 2007 (oral)
T.M. Mannan, N. Jodeiri, J. Mmbaga, R.E. Hayes and S.E. Wanke, Catalytic radiant heaters for fugitive methane and BTEX combustion, <i>55th Canadian Chemical Engineering Conference</i> , Edmonton, Oct. 2007 (oral)
R.E. Hayes and S.E. Wanke, Catalytic combustion for the elimination of methane, BTEX and other VOC, Air Issues Forum and Poster Session for the Upstream Oil and Gas Industry, Calgary September 24, 2007. (oral)
R.E. Hayes, N. Jodeiri, T. Mannan, J. Mmbaga and S.E. Wanke, Designing Catalytic Radiant Heaters for Fugitive Methane and BTEX Combustion, <i>1<sup>st</sup> International Congress on Green Process Engineering</i> , Toulouse, France, April 24 2007 (poster with refereed proceedings)
R.E. Hayes and S.E. Wanke, Catalytic combustion for the elimination of methane, BTEX and other VOC, <i>Air Issues Forum and Poster Session for the Upstream Oil and Gas Industry</i> , Calgary November 23, 2006 (oral)
J. Mmbaga, T.M. Mannan, N. Jodeiri, S.E. Wanke and R.E. Hayes, Modelling of catalytic radiant heaters, <i>COMSOL Users Conference 2006</i> , Las Vegas October 2006. (poster with extended abstract)
R.E. Hayes and S.E. Wanke, Catalytic combustion for the elimination of methane, BTEX and other VOC, <i>Air Issues Forum and Poster Session for the Upstream Oil and Gas Industry</i> , Calgary November 23, 2006. (oral)
H. Hammawa, T. Mannan, J. Mmbaga, B. Liu, S.E. Wanke and R.E. Hayes, Using counter-diffusive catalytic radiant heaters for fugitive methane and BTEX combustion, <i>19<sup>th</sup> Canadian Symposium on Catalysis</i> , Saskatoon, May 2006. (poster)
R.E. Hayes and S.E. Wanke, Catalytic combustion for the elimination of methane, BTEX and other VOC, <i>Air Issues Forum and Poster Session for the Upstream Oil and Gas Industry</i> , Calgary September 28, 2005. (oral)

**Other (Including Technical Reports, Non-Refereed Articles, etc.):**

Three end of year reports prepared for CAPP/PTAC/ERAC and distributed to partners. Further, a number of progress reports have been made to the partners and the ERAC committee. These primarily consist of emailed updates and teleconferences.

4.3 How many of the papers and presentations listed above were co-authored by the partners?

\_\_\_\_\_

**4.4 Patents and Licences**

Please provide the **number** of patents (filed and issued) and licences to date arising from the research project supported by the grant in the table below. (Provide details in 4.5.)

Not applicable

**- OR -**

None Yet Filed/Issued

Description	Number of Patents				TOTALS
	CANADA	U.S.	EP	OTHER	
# of Patent Applications Filed					
# of Patents Issued					

# of Licences  (Provide details in 4.5.)

4.5 Please provide details (titles, patent application number, patent number...) about the above listed patent applications, patents, and licences under the corresponding headings.

**Patent Applications Filed:**

**Patents Issued:**

**Licences: (licenceses, exclusive/non-exclusive...)**



## 4.6 Identify the tangible results obtained during the research project. (Select all that apply.)

- Prototype/pilot  
 New product  
 New process  
 Improved product  
 Improved process  
 Contribution to policy or regulation  
 Other (specify) \_\_\_\_\_

Briefly describe these outcomes.

The ability of the counter diffusive catalytic reactor to destroy BTEX compounds in a typical glycol dehydrator emission stream has been demonstrated. The rate limiting step in the reaction is the rate of mass transfer of oxygen through the boundary layer at the catalyst pad surface. The mass transfer rate can be increased by inducing some forced convection. The water present in the emission stream is not expected to be a significant problem provided that the stream enters as a vapour.

## 4.7 Prospects for the transfer of the results to the user sector

Describe how the results achieved are being transferred to the user sector and the prospects for their commercial/industrial exploitation.

The results are currently being transferred to the user sector via reports and presentations. Based on the results to date, we expect that there will be the potential for a field trial.

## 5. Problems Encountered

## 5.1 Identify the main problems encountered during the research project. (Select all that apply.)

- Technical or scientific problems  
 Problems with direction of research or findings  
 Equipment and facilities  
 Staffing issues (including students)  
 Funding problems  
 Partner withdrew from project  
 Partner interaction issues  
 Other (specify) \_\_\_\_\_

- OR -

No problems occurred during the research project

## 5.2 Briefly describe the main problems identified above and the steps taken to resolve each one.

Some problems with gas analysis that proplonged obtaining reproducible results for the slippage studies. There was also some delay because one PhD student took a maternity leave. An MSc

student who was supposed to join the project in January 2007 was unable to obtain a study permit. During the project, several PDF and RA left for employment.

## 6. Collaboration with Partners

### 6.1 Who initiated this CRD project?

- The university researcher  
 The industry partner  
 Shared initiation (university/industry)  
 Other (Specify): \_\_\_\_\_

### 6.2 In what way were the partners directly involved in the project? (Select all that apply.)

- Partners were not involved in the project apart from their financial and/or in-kind contribution  
 Partners were available for consultation  
 Partners provided facilities  
 Partners participated in the training  
 Partners discussed the project regularly with the university team  
 Partners received training from university personnel  
 Number of meetings during the period covered by this report: 7  
 Partners were involved in the research

### 6.3 Describe the partners' involvement and comment on the collaboration.

All of the supporters were involved in the collaboration. The primary role of PTAC is to administer the funding. They organised the annual *Air Issues Forum and Poster Session for the Upstream Oil and Gas Industry* where results were presented to a broad industry audience. Scott-Can has provided technical support and materials. New Paradigm has provided industry perspectives and provided field test data. Husky Energy has provided technical information and advice. As noted, meetings to exchange information have been held with all parties.

### 6.4 Were all cash commitments received from the partner?

- Yes  
 No

### 6.5 Was any in-kind committed to this project?

- Yes  
 No

- 6.6 For cash and in-kind received, please enter the amounts below, along with the amount of cash and in-kind committed in the original proposal. If no in-kind was received, please enter "0". Where in-kind was not committed enter "n/a".

	Amount Committed	Total Amount Received
<b>Cash</b>	212 175	212 175
<b>In-Kind</b>	8000	8 000

- 6.7 Describe the in-kind received and explain variations between commitment and actual cash and in-kind contribution if applicable.

Scott-Can provided several heaters and some instrumentation, which was valued in the proposal at \$2000, but has exceeded this amount in practice. Scott-Can, Husky and New Paradigm all provided consultation and technical data. This contribution had been assessed at \$2000 for each supporter in the original application.

## 7. Impact on Researcher

- 7.1 What impact has the project had on your teaching? (Select all that apply.)

No impact

**- OR -**

Creation of new courses

New content for existing courses

Use of real world examples

Guest lectures from partners

New equipment/material

Other (Specify): \_\_\_\_\_

- 7.2 What impact has the project had on your research? (Select all that apply.)

Influenced the direction to more industrial relevant topics

Opened up new opportunities for research beyond the original objectives

Other (Specify): \_\_\_\_\_

## 8. Financial Information

An up-to-date Grants in Aid of Research Statement of Account (Form 300) must be provided for both the NSERC contribution and any partner contributions to this project. These should cover the full period of the project. Please forward them with your report if available, or ask your finance department to forward them directly to NSERC.

**In addition**, the following financial table must be completed.

- 8.1 What is the balance remaining at the end of the project?

**\$ 0.23** \_\_\_\_\_

Budget Item	Total Budget	Actual Expenditures
<b>Salaries and Benefits</b>		
a) Students	105 000	118 180.24
b) Postdoctoral fellows	99 000	68 111.43
c) Technical/professional assistants	99 000	133 000.27
d) Other (specify)		
<b>Equipment or facility</b>		
a) Purchase or rental	27 000	14 161.80
b) Operation and maintenance costs		
c) User fees		
<b>Materials and supplies</b>		
a) Materials and supplies	24 000	12 273.25
<b>Travel</b>		
a) Conferences	7500	15 321.00
b) Field work		
c) Collaboration/consultation	7500	7951.78
<b>Dissemination Costs</b>		
a) Publication costs		
b) Other (specify)		
<b>Other (specify)</b>		
a)		
b)		
<b>Totals</b>	369 000	368 000.77

Please provide detailed explanations for any significant deviation from the budget.

No significant deviations were made. Some internal reallocation among classes of HQP was made, resulting in more student and less PDF support. Overall 87% of the budget was used for HQP. Other expenses were all relatively minor.

## 9. Future Plans

9.1 What links are you maintaining with the partners? (Select all that apply.)

- No contact with the partners  
 Collaborating with the partners on the same research  
 Collaborating with the partners on other research  
 Collaborating with other partners on the same research  
 Continuing the research without partners

- 9.2 Please describe any follow-up or related work that will be undertaken as a result of this project, and who will be involved in this work (including partners).

This project will continue for approximately one more year, to allow time for the two graduate students currently involved on the project time to finish. The work will include more catalyst development work (Gangyu Huang), plus a detailed modelling study using the models developed, primarily as a tool to elucidate the experimental findings. Industrial implementation will depend on the level of interest shown by the appropriate companies.