**EVALUATION REPORT OF PH.D THESIS**

**Vivek Kumar**

**1.** Name of student: ………..…………………………………………………………. **Title of thesis: Economic plantwide control techniques applied to a reactor-separator-recycle process (Submitted Jan. 2019)**

**2.** Roll No.:…

**3.** Department:………**Chemical Engineering**………………………….

**4.** General features of thesis

**(i)** Organization and Presentation:

The thesis consists of seven chapters; an introduction (Chapter 1), five main chapters and a Summary and future work chapter (Chapter 7). The five main chapters are all very similar to accepted or planned journal papers. Two of the papers have already been published, one is accepted and one is under review in Industrial & Engineering Chemistry Research. in addition one paper has been submitted to Journal of process Control, which is considered a more prestigious journal within the area of process control.

**Chapter 2**. Hill climbing for plant wide control to economic optimum*. Published: I&EC 2014*

**Chapter 3**. Real Time Optimization of a Reactor-Separator-Recycle Process I: steady state modelling, *Published: I&EC 2018*

**Chapter 4**. Real Time Optimization of a Reactor-Separator-Recycle Process II: Dynamic Evaluation. *Accepted: I&EC 2019*

**Chapter 5.** Invariants for Optimal Operation of a Reactor-Separator-Recycle Process. *Under review: JPC*

**Chapter 6.** Inferential Self Optimizing Control of a Reactor-Separator-Recycle Process. *Under review: I&EC*

Thus, the thesis is essentially a collection of papers. The papers are generally very well written and it is easy to follow the arguments. The main topic of the thesis is plantwide control using classical advanced control structures, like cascades and selectors. Such structures are viewed as “old-fashioned” by many, but they nevertheless remain the workhorse of the process industries. It is therefore about time, after about 60 years of neglect, that the academic community makes an effort to analyze and understand such structures and provide systematic methods for how they should be designed. The thesis contributes to this for the important case of reactor-recycle processes.

**(ii)** Is the quality of work comparable YES

with that in other universities of repute?

**(iii)** Does the thesis embody any YES

new ideas with original thoughts?

**5. Comments** (The examiner may give details on additional sheet(s), if required.)

1. Corrections for punctuation, grammar, spelling, typographical errors or language:

NONE

1. Technical content of the thesis:

The basis for the thesis is that optimal operation is achieved firstly by controlling the active constraints. Next, for the unconstrained degrees of freedom, optimal operation is achieved by driving the gradient of the cost function (dJ/du) to zero. For the reactor-separator process there is one unconstrained degree of freedom (u), which can be considered to be, for example, the recycle rate R or the reactor composition.

In Chapter 2, optimal operation is achieved by simply estimating the gradient experimentally by perturbing the input u and measuring the cost function J. The chapter is based on what they call “Shinskey’s hill climber” but as pointed out in Chapter 1 this method is similar to many other methods for extremum seeking control.

Chapter 3 uses real-time optimization (RTO) which uses a detailed nonlinear model of the plant. The chapter discusses how to update the model parameters and how to implement the optimization for the reactor-recycle case study. Chapter 4 discusses how to implement the results from RTO in practice using conventional advanced control, which emphasis on how to use selectors to handle changes in active constraints.

All these chapters are well written and contain interesting result. However. Since these chapters have already been published or accepted, there is not too much point in providing further comments.

Chapter 5 proposes invariants for optimal operation and the closely related Chapter 6 in their implementation are still under review. The basis for this chapter is the idea of self-optimizing control (SOC), which is to move the optimization into the control layer by controlling the right self-optimizing CV at a constant setpoint. The ideal self-optimizing variable is the gradient, and chapter 5 finds “global” self-optimizing for the specific reactor-separator case study. It only required measuring the reactor composition and requires no online optimization. In many cases, the optimal policy is simply to keep the ratio between A and B in the reactor constant. However, it should be noted that this is a rather specific case study with reaction A+B=C and with no inerts in the feed, so with no need for purge. Nevertheless, it’s very interesting that one analytically can find such as global SOC variable for this case.

Chapter 6 proposes how the results from Chapter 5 can be implemented in the control system. Based on physical arguments, it’s argued that the top distillation column temperature can be used instead of the ratio between A/B compositions. The proposed control strategy is compared with the conventional strategy with constant composition of B in the reactor, and it’s found that significant economic benefits can be achieved, for example, an increase in production rate of 5%.

The concluding chapter 7 is rather short, It is suggested that a hill-climber that updates the setpoint for the SOC variable setpoint is an ideal combination for practical implementation

1. Highlights and strong/weak points in the thesis:

The main strong point of the thesis is that it addresses important issues and contains new results related to the practical implementation advanced process control and optimal operation. The weak point is that the case reactor-recycle case study is quite specific and it is not clear how the results apply to other cases.

**6. Suggestions** (The examiner may give details on additional sheets.)

**None**

**7. Specific Recommendation**

(Please cross out any two paras out of the following)

(i) The thesis is acceptable in the present form for the award of the Ph.D Degree.

~~(ii) The thesis is acceptable and the corrections, modifications and improvement suggested by me be incorporated in the thesis to the satisfaction of the oral board.~~

 ~~(iii) The thesis needs technical improvement/modifications which must be carried out to my satisfaction. Student’s written response to the above suggestions be sent to me and I will give my reply to the same within two weeks of its receipt. This is necessary before I recommend the thesis for acceptance.~~

Trondheim 14 March 2019



(Signature of the Examiner)

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