Operational Model for C3 Feedstock Optimization on a Polypropylene Production Facility

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Project Overview

Polypropylene production facility

- Chemical and refinery grade feedstocks with different prices and propylene purities.
- Best operation will balance production rate with costs of feedstocks, maximizing plant throughput.

- Objectives:
  - Development of a Non-linear Programming (NLP) model to assess the benefits of a better balance of RG and CG feedstocks for single or multiple production orders.
  - Determine operation rates for a schedule of multiple production orders within a 3-month timeframe.
  - Implement user-friendly interface (GAMS model / MS-Excel)

Process and Problem Description

- Process components
  - Distillation column (propylene/propane)
  - Polypropylene Reactor
  - Loop Feed tank
  - Mixers/splitters

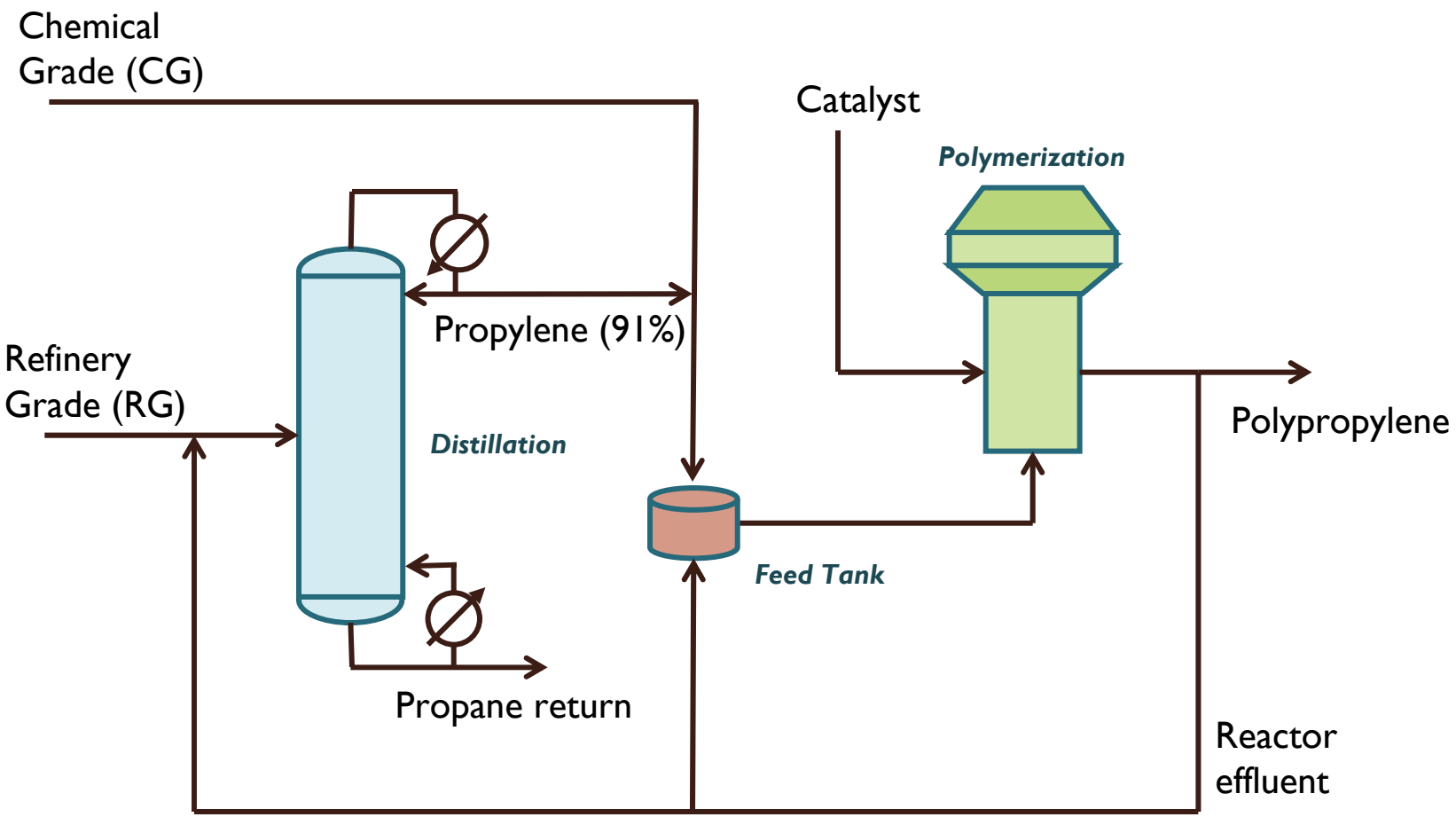
- Feedstock streams
  - Refinery Grade (RG) ~79% propylene
  - Chemical Grade (CG) ~95% propylene

  Maximizing the amount of RG may not be the best economic option

- Kinetics of the Polypropylene Reactor
  - Limits on catalyst flow and yield

- Objective:
  - Assess the benefits of a better balance of RG and CG feedstocks for each product.

Process and Problem Description



Single/Multiple Product Models

- Single Product Model
  - Maximize profit in terms of $/hr
  - Best production rate with minimum cost of feedstocks.

- Multiple Product Model
  - Multiple orders of different products
  - Production sequence given beforehand
  - Profit ($) = selling prices – feedstock costs
    + propane return – others
  - Solution gives best production rates with minimum costs for each product

Mathematical Model (NLP)

- Maximize Profit

- Constraints on each time interval:
  - Material balances
  - Min/Max flow rates
  - Constraints on composition of Propane Return, Distillation Overhead & Reactor Feed
  - Limits on catalyst yield and flow
  - Availability of Chemical Grade
  - Specifications on splitter feed and recycle rate

- Decision variables:
  - Production rate of polypropylene
  - Flowrates and compositions (propylene / propane) at each stream
  - Catalyst flow

Preliminary Results

NLP formulation implemented in GAMS

Single Product Model

- Model size: 31 variables, 40 constraints
- Solved with CONOPT and BARON in less than 1 CPU s.
- Improved hourly profit by ~1.5%

Multiple product model

- Mid-size example with 20 products, 5 families
- Model size: 727 variables, 986 constraints
- Solved by CONOPT in ~9 seconds.
- Different time horizons tested to measure the TRADEOFF of

PRODUCTION COSTS versus PRODUCTION RATES

- Added "slack" product to assess the benefits of extra production when schedule finishes early → GAINED OPPORTUNITY

Preliminary Results

Tradeoff of Production Costs / Production Rates

Time Horizon		28 days				31 days			34 days		
Product	Req. (cars)	% max RG	% RG	% CG	% max prate	% RG	% CG	% max prate	% RG	% CG	% max prate
1	10	97.45	62.28	37.72	100.00	76.31	23.69	81.30	81.15	18.85	75.66
2	10	97.45	62.28	37.72	100.00	76.31	23.69	81.30	81.15	18.85	75.66
3	34	97.45	62.28	37.72	100.00	76.31	23.69	81.30	81.15	18.85	75.66
4	2	97.45	62.28	37.72	100.00	76.31	23.69	81.30	81.15	18.85	75.66
5	8	97.88	63.43	36.57	98.38	78.72	21.28	78.41	81.15	18.85	75.66
6	2	97.45	62.28	37.72	100.00	77.74	22.26	79.56	81.15	18.85	75.66
7	30	97.45	62.28	37.72	100.00	76.45	23.55	81.12	81.15	18.85	75.66
8	2	97.45	62.28	37.72	100.00	77.74	22.26	79.56	81.15	18.85	75.66
9	14	97.45	62.28	37.72	100.00	76.31	23.69	81.30	81.15	18.85	75.66
10	10	97.45	62.28	37.72	100.00	76.31	23.69	81.30	81.15	18.85	75.66
11	4	97.45	62.28	37.72	100.00	76.31	23.69	81.30	81.15	18.85	75.66
12	2	97.45	62.28	37.72	100.00	77.74	22.26	79.56	81.15	18.85	75.66
13	12	97.47	62.32	37.68	99.94	78.02	21.98	79.23	81.15	18.85	75.66
14	7.8	97.47	62.32	37.68	99.94	78.02	21.98	79.23	81.15	18.85	75.66
15	0.2	97.47	62.32	37.68	99.94	78.02	21.98	79.23	81.15	18.85	75.66
16	16	97.45	62.28	37.72	100.00	77.74	22.26	79.56	81.15	18.85	75.66
17	3	97.45	62.28	37.72	100.00	77.74	22.26	79.56	81.15	18.85	75.66
18	1	97.45	62.28	37.72	100.00	77.74	22.26	79.56	81.15	18.85	75.66
19	18	98.64	65.58	34.42	95.46	80.09	19.91	76.84	81.15	18.85	75.66
20	2	97.45	62.28	37.72	100.00	77.74	22.26	79.56	81.15	18.85	75.66
Total Time (h)					**672.00**			**744.00**			**788.77**
Optimal solution (PROFIT)					**88.1 MU**			**100 MU**			**103.2 MU**

Preliminary Results

Gained Opportunity

Time Horizon		31 days			31 days w/Gain Opportunity			
Product	Req. (cars)	% RG	% CG	% max prate	% max RG	% RG	% CG	% max prate
1	10	76.31	23.69	81.30	97.45	62.28	37.72	100.00
2	10	76.31	23.69	81.30	97.45	62.28	37.72	100.00
3	34	76.31	23.69	81.30	97.45	62.28	37.72	100.00
4	2	76.31	23.69	81.30	97.45	62.28	37.72	100.00
5	8	78.72	21.28	78.41	97.45	62.28	37.72	100.00
6	2	77.74	22.26	79.56	97.45	62.28	37.72	100.00
7	30	76.45	23.55	81.12	97.45	62.28	37.72	100.00
8	2	77.74	22.26	79.56	97.45	62.28	37.72	100.00
9	14	76.31	23.69	81.30	97.45	62.28	37.72	100.00
10	10	76.31	23.69	81.30	97.45	62.28	37.72	100.00
11	4	76.31	23.69	81.30	97.45	62.28	37.72	100.00
12	2	77.74	22.26	79.56	97.45	62.28	37.72	100.00
13	12	78.02	21.98	79.23	97.45	62.28	37.72	100.00
14	7.8	78.02	21.98	79.23	97.45	62.28	37.72	100.00
15	0.2	78.02	21.98	79.23	97.45	62.28	37.72	100.00
16	16	77.74	22.26	79.56	97.45	62.28	37.72	100.00
17	3	77.74	22.26	79.56	97.45	62.28	37.72	100.00
18	1	77.74	22.26	79.56	97.45	62.28	37.72	100.00
19	18	80.09	19.91	76.84	97.45	62.28	37.72	100.00
20	2	77.74	22.26	79.56	97.45	62.28	37.72	100.00
SLACK	--				95.03	60.96	39.04	99.88
Total Time (h)				**744.00**				**744.00**
Optimal solution (PROFIT)				**100 MU**				**109.1 MU**

Conclusions and Future Work

CONCLUSIONS

- Integrated plant formulation developed including distillation and polymerization processes in a single model.
- One or multiple products can be handled.
- Single product model improved hourly profit by ~1.5% by balancing production rate and feedstock costs.
- Multiple product model shows realistic tradeoff on RG/CG feedstocks costs vs production rates (depending on available time).
- Loss/gain opportunity preliminary results show the convenience of maximum capacity production whenever possible.

FUTURE WORK

- Inclusion of more detailed distillation and polymerization models
- Revision of kinetic reaction modeling alternatives
- Larger problem instances
- Improve user interface for operational use:
  - Model parameterization through Excel interface
  - VBA macros to connect Excel / GAMS model