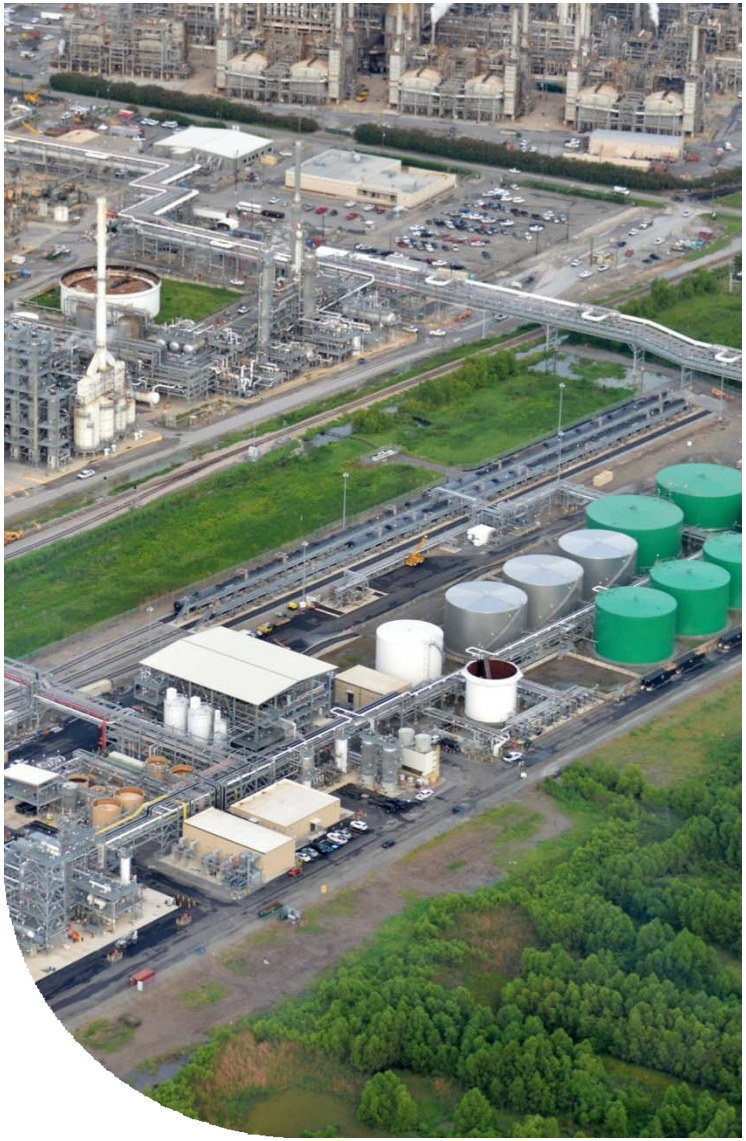


James Rekoske

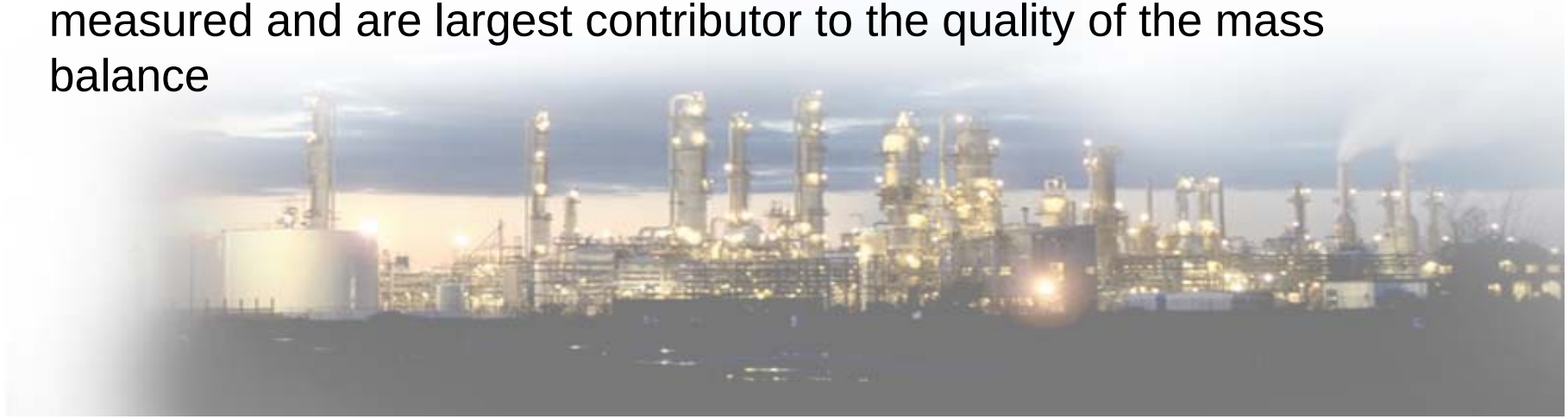
Mass Balance Approach for Co-processing

February 7th, 2017 | CARB Meeting | Sacramento, CA

UOP Experience with Unit Mass Balances

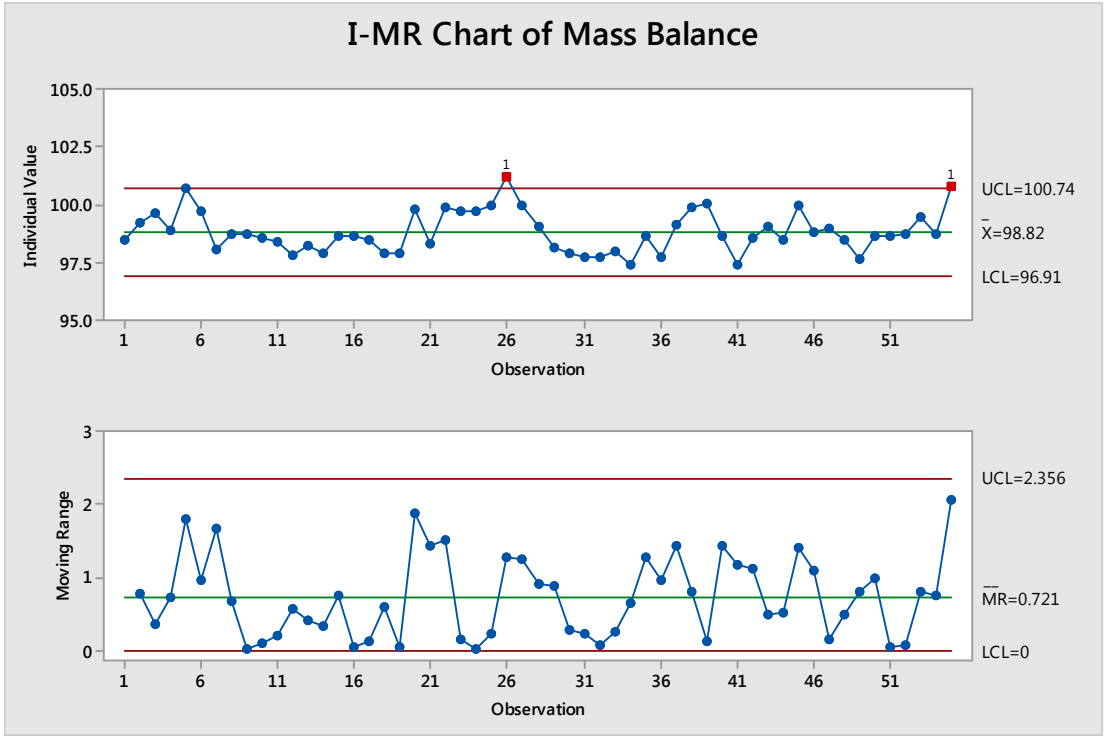
- UOP uses mass balances for daily unit monitoring, troubleshooting, and performance testing of FCC and DHT Units
  - Challenges include occasional error in the inputs which can have an impact on calculated outputs
  - Data collection frequency and duration can also have an impact on the accuracy of the material balance
  - FCC units typically have a material and energy balance conducted for a single day of operation, using laboratory data collected during a shift coupled with daily averages of process data

- Feed, process, and product streams flowrates on the unit are measured and are largest contributor to the quality of the mass balance



Definition of a Good Mass Balance

- In UOP's experience good unit mass balances typically consist of:
  - Mass Balance – 98-102 wt% - Confirms flow meters are correct
  - Hydrogen Balance – 98-102 wt% - Confirms lab data is correct (i.e. Gravity and Distillations)
  - If out of range, normal troubleshooting efforts will be undertaken to understand source of variation



Analyzing Commercial Co-processing Trial Mass Balance Data for Biocrude Feed Impacts

- Key
  - Long term testing is needed to accurately measure small shifts in yields
  - Conversion varies about 0.7 to 1.0 v% due to natural variation in measurements, catalyst activity, feed quality, cut points, etc
  - Because of this natural variation, many observations are needed to measure small yield shifts to desired accuracy

- Solution
  - Use simple models to adjust the raw data

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Proposed Approach for Measuring Biocrude FCC Co-processing Performance

- Measure
  - Baseline performance based on current or historical data without biocrude
- Model
  - Develop simple statistical regression model of yield relationships to conversion (and other parameters) with small and defined error bands based on observed commercial performance
- Test
  - Complete both pulse and long duration testing with biocrude to generate yield performance data with biocrude
- Tune
  - Incorporate a biocrude regression term into the original yield model and regress equations based on observed performance from test
- Predict
  - Use the model to predict performance with and without biocrude with current data to calculate yields attributable to the presence biocrude

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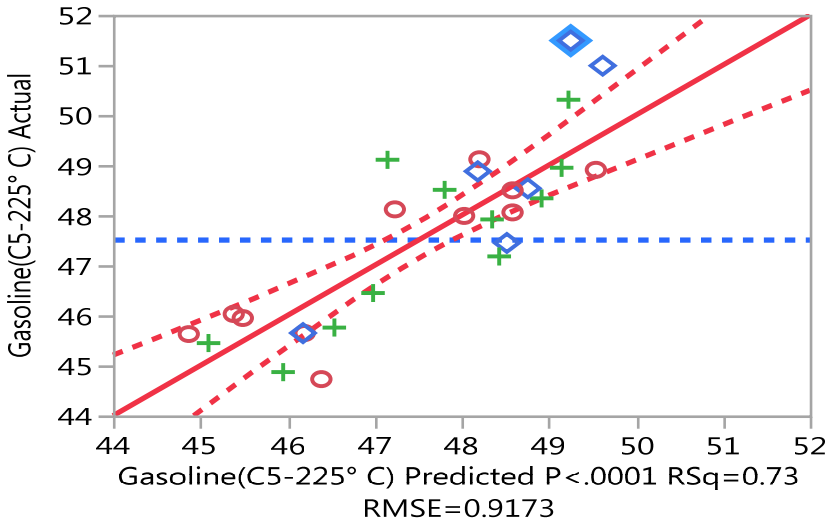
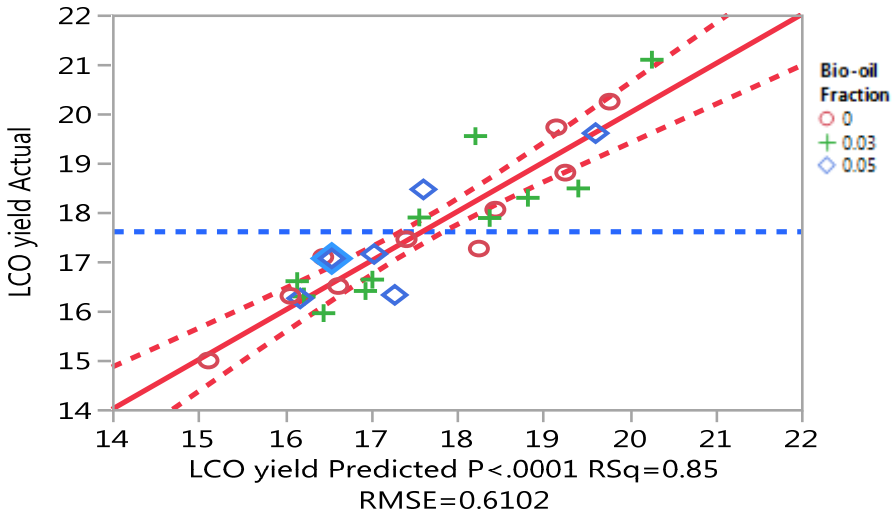
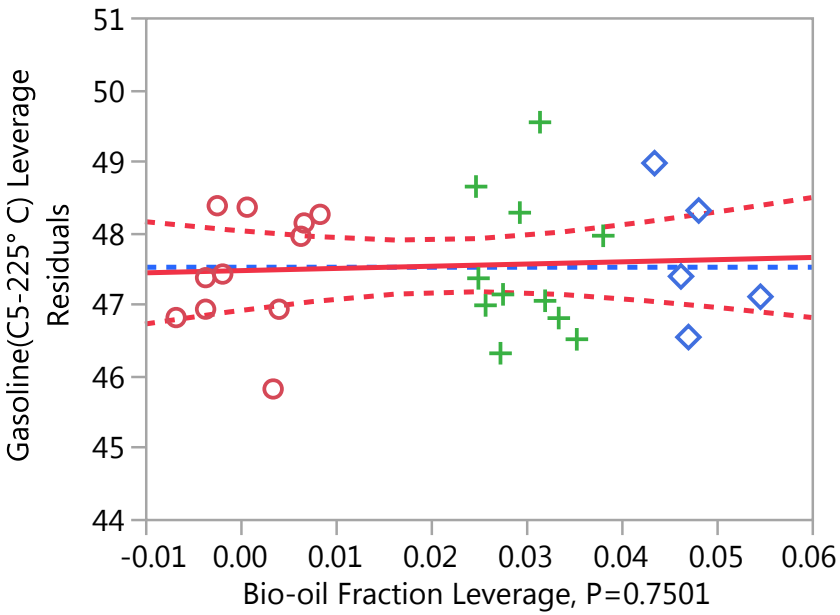
Hypothetical Example of Model Output

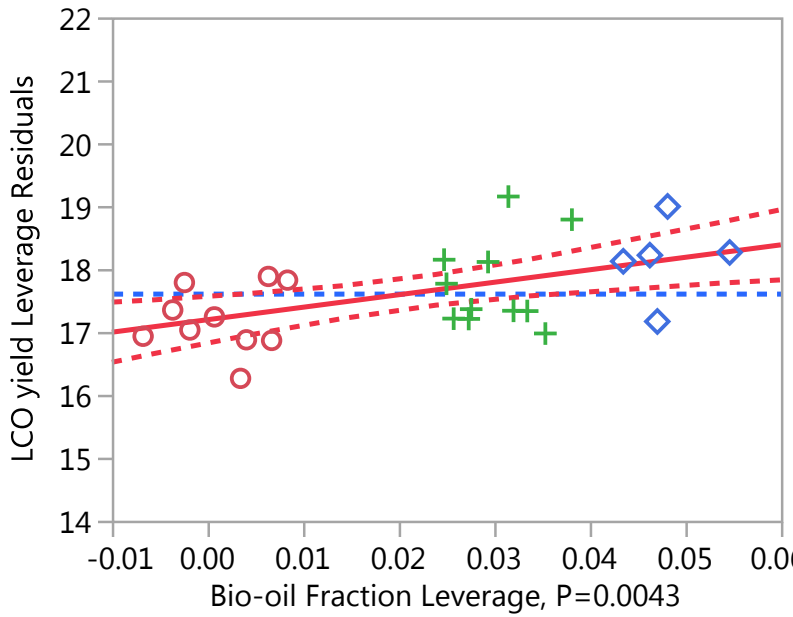
Gasoline Yield



LCO Yield





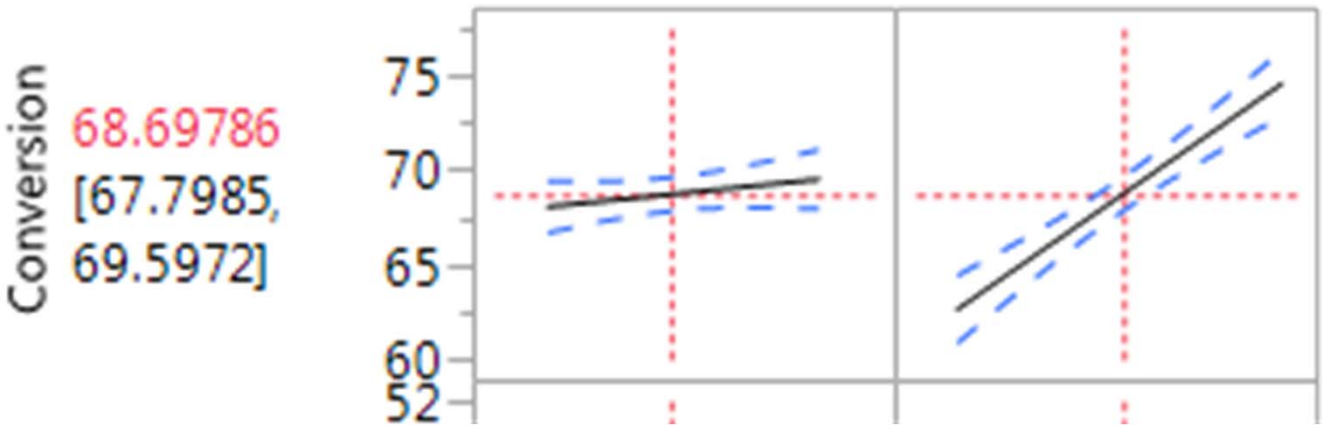



Q&A

Establishing Statistically Significant Trends

- Regression Example
  - Mass balance / yield data can be worked up to establish clear trends as a function of biocrude addition
  - Proposed simple linear model of key variables over modest ranges
  - Responses are “trained” on pre-test, post-test daily operations by simple regression
  - Fraction of Biocrude Feed: (FBF) is in each model to quantify yield shift (if any) and measure significance

- Possible Equation form
  - Conversion – FBF, Triser, Cat/Oil, Activity, VGOAPI, VGONitrogen, Throughput



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Typical FCC Yield Factors & Relationships

- Conversion – f(FBF, Triser, Cat/Oil, Activity, VGOAPI, VGONitrogen, Throughput)
- C_2- = f(FBF, Conversion, contact time, metals)
- LPG = f(FBF, Conversion, contact time, ZSM5, metals, PartialPressure)
- Gasoline & LCO = f(FBF, Conversion, contact time, ZSM5, metals, PartialPressure, T90)
- Coke – same variables, TFeed, TRX, CatCooler Duty

- Delta Coke – FBF, CCR/Cat/Oil, Cat/Oil, Tfeed, API, PartialPressure, Steam/Cat, Throughput (Flux, B/D)
- Cat Activity – Cat addition rate, metals (Na, V, Ca, K), Regen Temp
- CO_X – FBF, Cat/Oil, RegenPressure, TRegen, FlueGasCO

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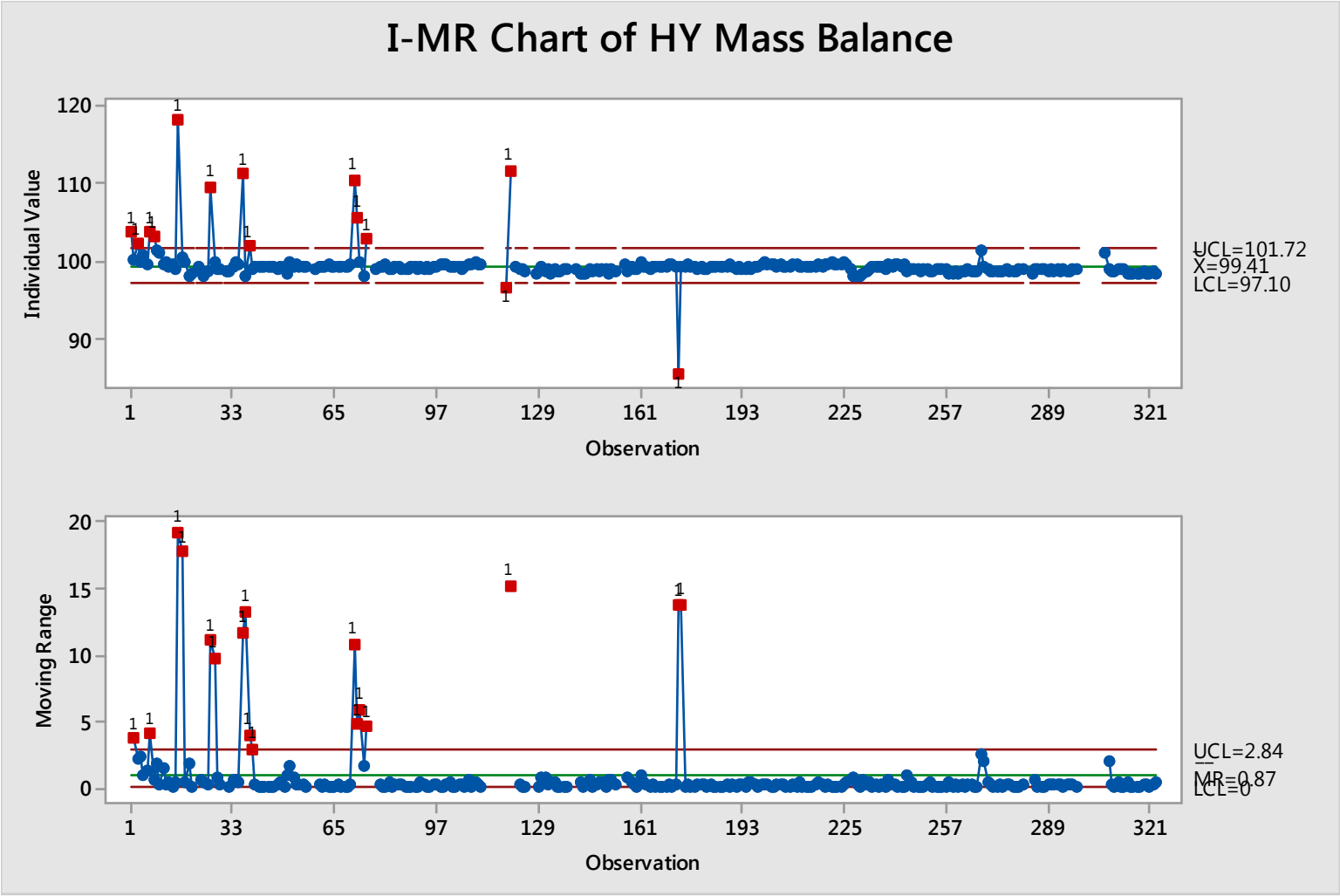
Typical HYT Mass Balance



Establishing Performance from a Co-processing Trial

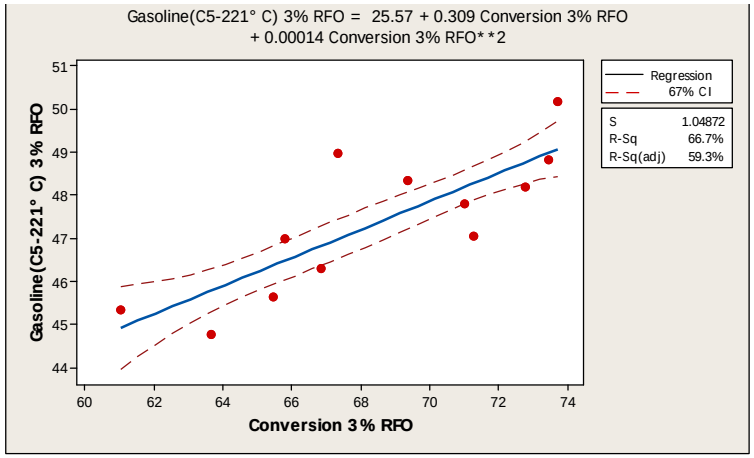
- Preparation
  - Establish baseline mass balance / performance values for a minimum of a month before the co-processing trial
    - It may be necessary to recalibrate instrumentation and work with the laboratory to ensure the analytical methods are being executed properly
    - Data should be collected prior to the trial for a time equal to, or greater than the proposed trial duration to best understand how the unit runs with and without biocrude and to provide basis for statistical regression and modelling

- Execution
  - Focus during the test will be on establishing trends and the impact that biocrude had on product yields during the test
    - For most commercial operations, the biocrude will only be added at 1-3 vol%
    - The raw yield and operational shifts measured will establish gross effects from co-processing, however it is understood that variations in feed, operating conditions, and catalyst that exist as part of normal operation can impact the results

How to measure the yield change in FCC

Collect existing data (could be hundreds of data points) on the FCC to establish relationships of product yields to conversion with small and defined error bands versus conversion

In FCC conversion is the dominant variable affecting yields as shown below with example confidence ranges



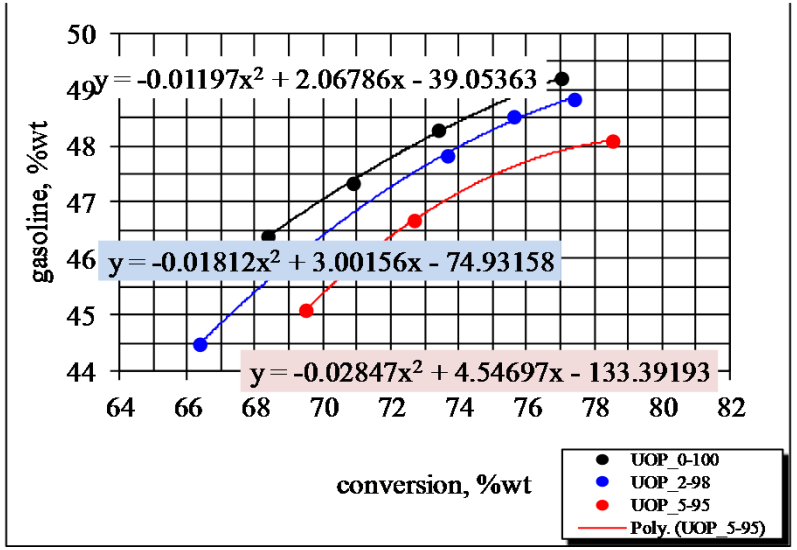
Estimate number of biocrude tests needed

Inputs: Estimated BC yield to fuels

Petroleum yield confidence interval

Required minimum fuel yield of BC

Required confidence level



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