Model-Based Sensor Placement for Component Condition Monitoring and Fault Diagnosis in Fossil Energy Systems – First Year Review

(PI) Raghunathan Rengaswamy (Speaker)

Texas Tech University

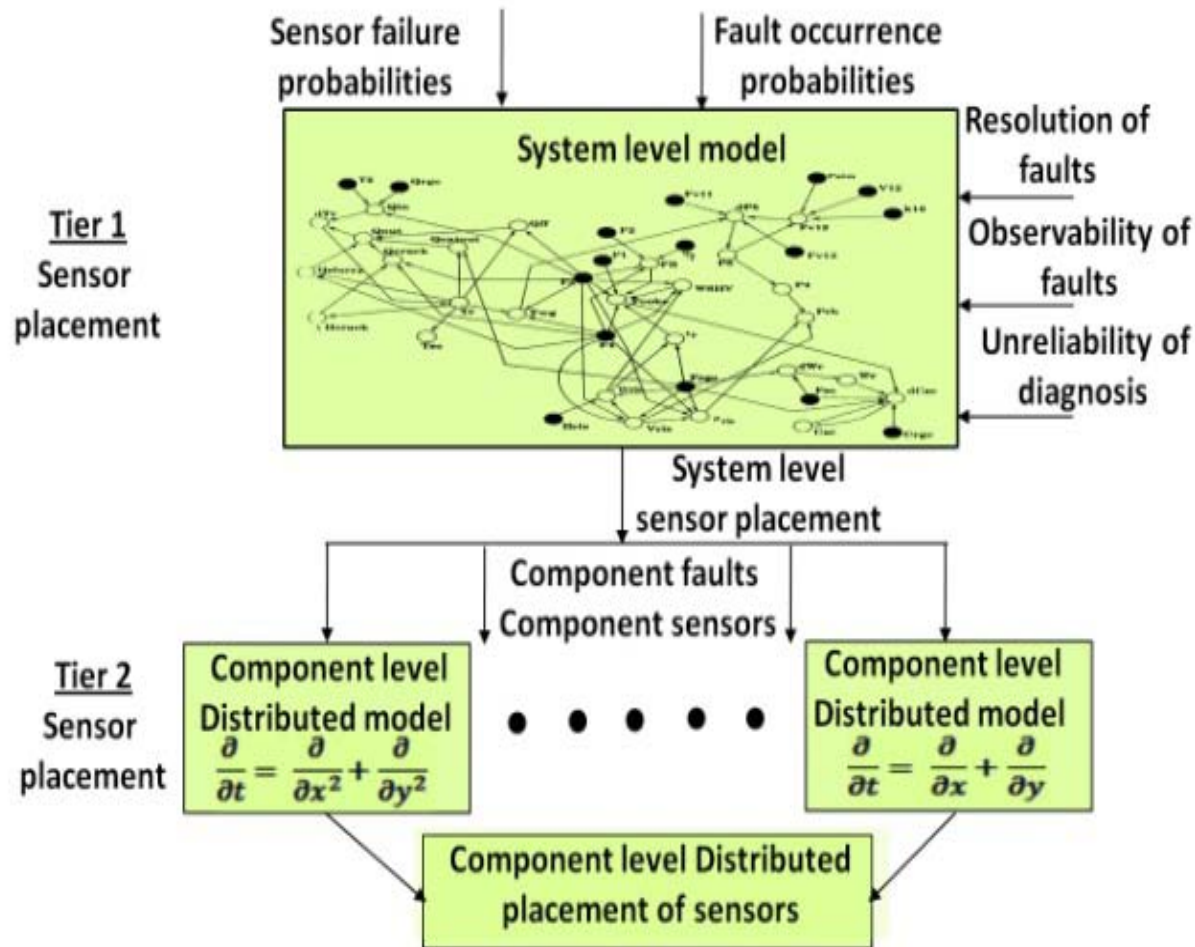(CO-PIs) Debangsu Bhattacharyya and Richard Turton

West Virginia University

Outline of the Talk

- Project Concept
- Technical Details
- Progress Made

PROJECT CONCEPT

Overall Concept – System Level Diagnosis and Unit Level Condition Monitoring

Tier-I Sensor Placement Work

- **Work Components**
  - Enhance prior work on models used at system level sensor placement with
    - Order of magnitude reasoning
    - Sensor alarm sequence
    - Generate highly informative fault sets using high fidelity dynamic simulations
    - Demonstrate the algorithm for an IGCC plant
    - Solution is identified through Integer Linear Programming (ILP) formulation
- **Major Deliverable**
  - A beta version software for Tier I placement
    - Customizable to any plant

Tier-I Modeling Work

- **Work Components**
    - Model enhancement for incorporating typical faults
        - Faults will be identified through reports/studies available in public domain on commissioning and operational experiences of the IGCCs all over the world
        - Critical faults that can improve the plant availability
        - Typical faults include blockage of the RSC, poisoning of the Claus catalyst, fouling of the key heat exchangers/steam generators, internal leakage in heat exchangers, frothing in the towers, etc.
        - Use of script, task, and additional unit operations to simulate faults
        - Sensor data from open literature
- **Major Deliverable**
    - A pressure-driven dynamic model incorporating the modeled faults

Tier- II Sensor Placement for Condition Monitoring

Tier-II Sensor Placement Work

- **Work Components**
  - Evaluate and enhance unknown input filter (UIF) approach for sensor placement in distributed systems
    - POD to convert PDE into ODE
    - Evaluate linearized UIF for condition monitoring
    - Enhance UIF for nonlinear systems using unscented transformation, if necessary
    - Couple UIF with Genetic Algorithms for optimization of sensor locations

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Tier-II Sensor Placement Work

- **Major Deliverable**
  - A beta version software for Tier II placement
   - Customizable to any unit

- **Evaluation**
  - Tier II sensor placement will be tested on two units for condition monitoring
    - Water Gas Shift Reactor
    - Gasifier

Tier-II modeling Work

- **Model enhancement and fault simulation**
  - Gasifier model will be enhanced with model of the slag flow, heat transfer in the slag layer, slag penetration into the refractory wall, and refractory heat transfer
  - Thinning of the refractory and slag penetration will be considered as faults
  - Consideration of coke formation and loss of catalyst activity as faults in the WGS reactors. Change in the thermal properties of the catalyst due to coke deposit will be considered.
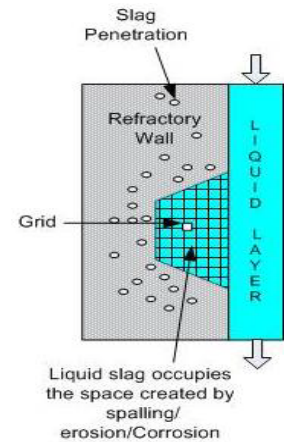
- **Major deliverables**
  - Enhanced gasifier and WGS reactor models

Tiers I and II Integration

- ## Integration
  - Identify integrated sensor placements
  - A diagnostic approach will be automatically generated when the sensor placement work is complete
  - Test the diagnostic system with sensor placements for system level faults and unit level condition monitoring

- ## Major Deliverable
  - A diagnostic system for a particular configuration of IGCC plant

BRIEF GENERAL BACKGROUND

Sensor Network Design Problem

- **Problem**
  - Which variables to measure and where (if spatial variation considered)
  - Which physical sensors (with different properties, cost) should be used
  - How many sensors (hardware redundancy) should be used for measuring a variable
  - What should be the frequency of sampling (measurement) for different variables
  - Maintenance policies

  Design as well as a Retrofit problem

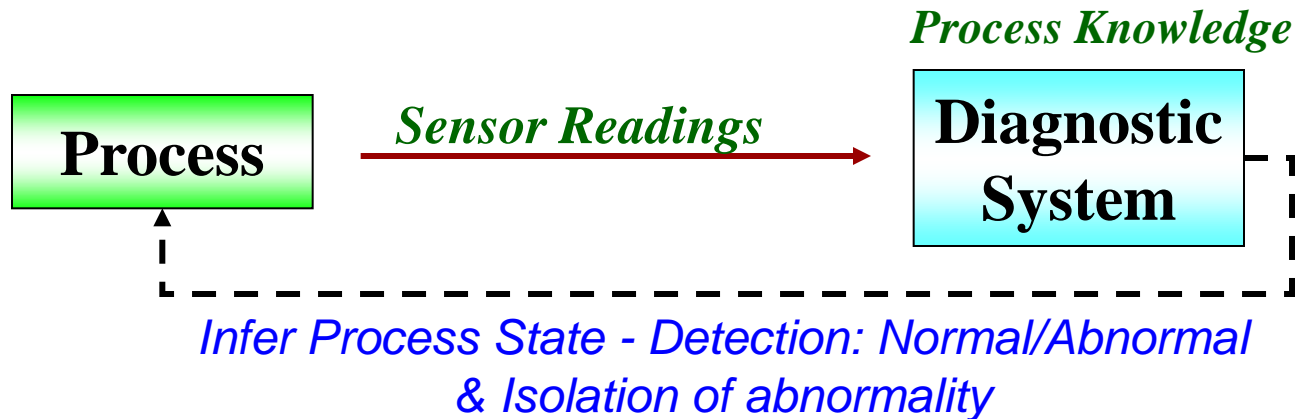# Sensor Network Design Problem

- **Why measure ?**
  - Control Perspective
    - Control important variables in the process
  - Process monitoring
  - Estimation Perspective
    - Reliable estimation of variables/parameters with high precision
  - Safety and environment regulations

  - *Fault detection and diagnosis*
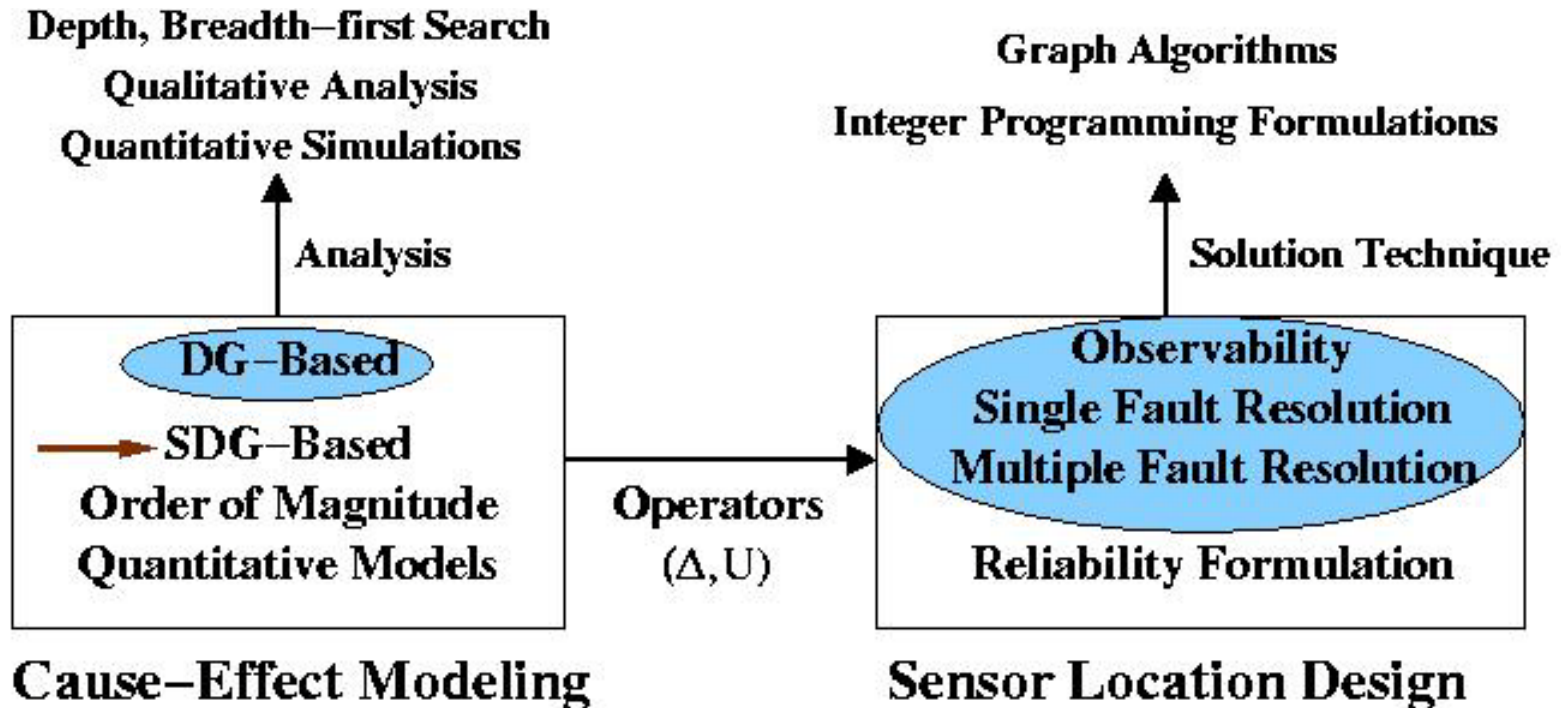   - *Monitor equipment condition and identify faults in a process*

Process Fault Diagnosis

- ## Interpreting current status of process
  - Utilizing sensor data & process knowledge
  - Detect and isolate abnormal situations (occur when process deviates significantly from normal regime)

Process Knowledge

| **Process** | → *Sensor Readings* → | **Diagnostic System** |

Infer Process State - Detection: Normal/Abnormal & Isolation of abnormality

- Impact of faults: 20 billion a year in process industries alone (Nimmo, CEP)
- Choice of appropriate sensor location critical for success of any fault diagnostic system
  - Which variables?
  - How many sensors?

Sensor Location: General Strategy

Depth, Breadth–first Search
Qualitative Analysis
Quantitative Simulations

Graph Algorithms
Integer Programming Formulations

Analysis

Solution Technique

DG–Based
SDG–Based
Order of Magnitude
Quantitative Models

Operators
(Δ, U)

Observability
Single Fault Resolution
Multiple Fault Resolution
Reliability Formulation

Cause–Effect Modeling

Sensor Location Design

END OF YEAR 1 REVIEW

End of Year 1 Progress

- **Assumptions, modifications and progress**
  - Fault simulations in a full IGCC plant model
  - Gasifier model being enhanced
  - A smaller plant model identified for system level sensor placement
  - One module of the system level sensor placement algorithm developed
    - To be tested on the smaller plant model identified
  - Water gas shift reactor model developed
  - One module of the distributed sensor placement algorithm developed
    - To be tested on the water gas shift reactor model

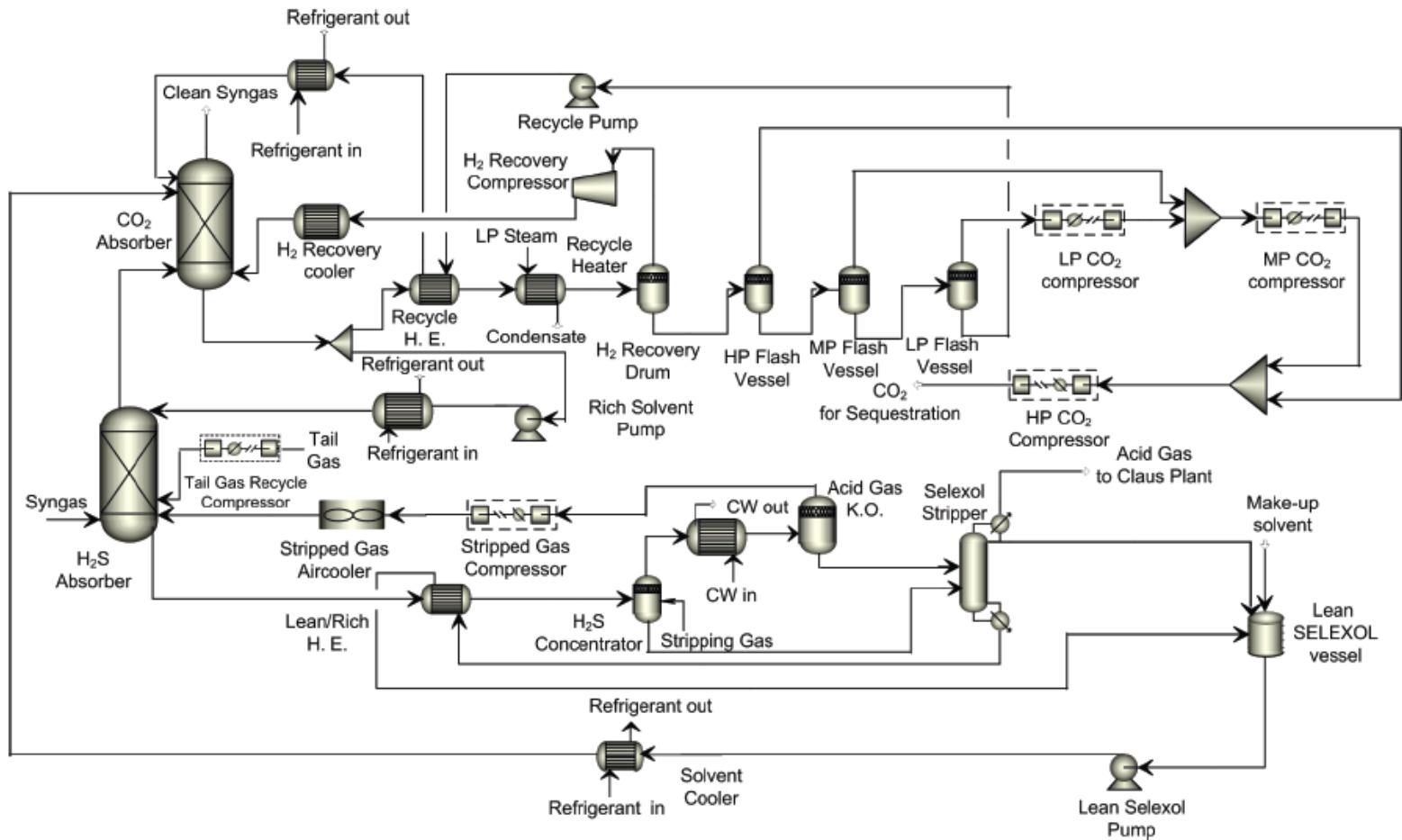# PLANT-WIDE SENSOR PLACEMENT

Sensor Placement Algorithm

For a system with:

- ❑ M number of possible faults.

- ❑ N number of process variables.

- ❑ $S_1 \quad _N$ be the set of sensors.

    where,

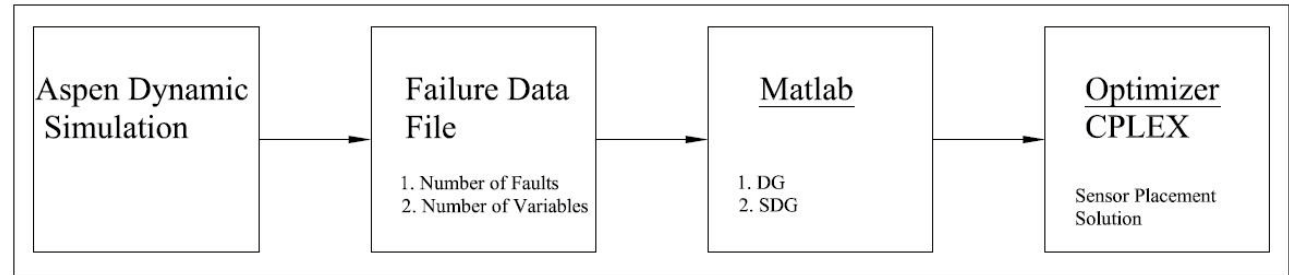$$S_j = \begin{cases} 1 & if\ j^{th}\ sensor\ is\ selected \\ 0 & otherwise \end{cases}$$
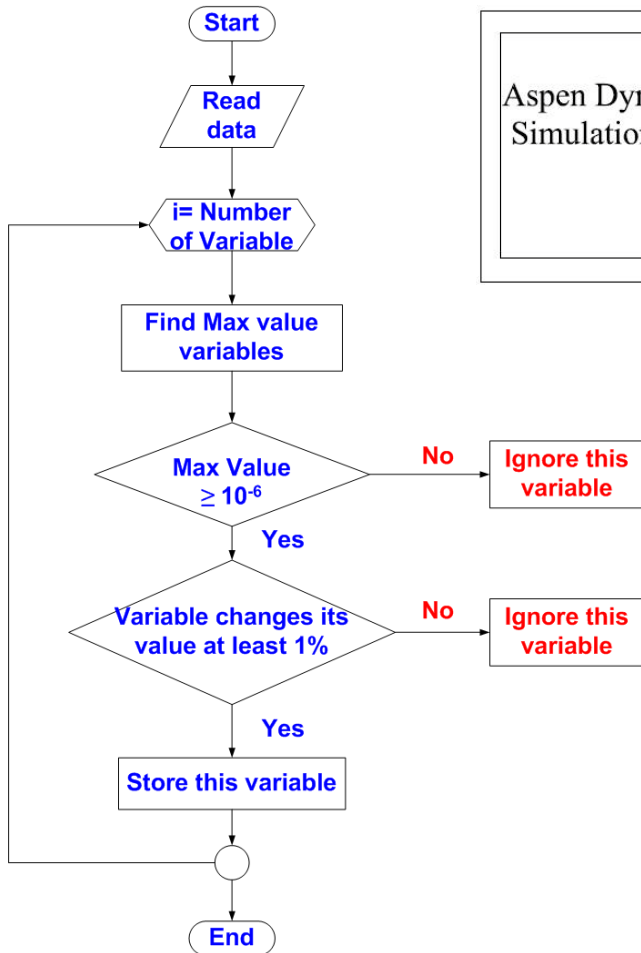
Sensor Placement for Selexol Plant

SELEXOL unit and the CO_2 compression section.

(Bhattacharyya, Turton, & Zitney, 2011)

Sensor Placement for Selexol Plant

Minimum Set Cover Sensor Placement Design

Number of faults	14
Number of Variables	1917

Variable Screening

Sensor Placement for Selexol Plant

Fault Name	Number of Variables That Respond
Deposition in CO_2 Absorber	14
Deposition in H_2S Absorber	14
Deposition in Selexol Stripper	6
Leakage in H_2 Recovery Flash Vessel	43
Leakage in HP Flash Vessel	14
Leakage in MP Flash Vessel	19
Leakage in LP Flash Vessel	24
Leakage in H_2S Concentrator	12
Fouling in Recycle H.E.	387
Fouling in Lean/Rich H.E.	246

Sensor Placement Algorithm

IPP formulation:
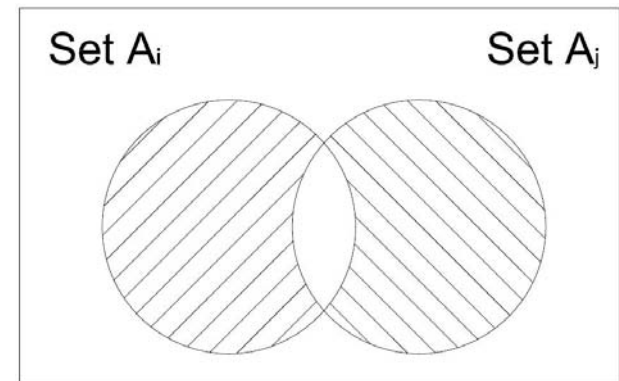
$$min \sum_{j}^{N} w_j S_j$$

$$\text{S.T.} : AS^T \geq b$$

Where W is a weight vector for sensor, i.e.

$$W = \begin{bmatrix} w_1 & w_2 & w_3 & w_3 & \cdots & w_N \end{bmatrix}_{1 \times N}$$

$$A = \begin{bmatrix} 1 & 0 & 0 & 1 & \cdots & 1 \\ 0 & 0 & 1 & 1 & \cdots & 1 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 1 & 0 & 1 & \cdots & 1 \end{bmatrix}_{M \times N} \quad \& \quad b = \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix}_{M \times 1}$$

Resolution Problem

(Raghuraj, Bhusan, & Rengaswamy, 1999)

$$B_{ij} = A_i \cup A_j - A_i \cap A_j$$

$$A_{(M + {}^M C_2) \times N} \quad \& \quad b_{(M + {}^M C_2) \times N}$$

Sensor Location: Reliability Maximization

- Minimize Unreliability: probability of a fault occurring and remaining undetected
- Unreliability of fault i is:

$$U_i = f_i \prod_{j=1}^{n} (s_j)^{(b_{ij} x_j)}$$

where,

f_i = occurrence probability of fault i,

s_j = failure probability of sensor j,

x_j = number of sensors measuring variable j,

b_{ij} = 1, if fault i affects variable j

n = number of measurable variables

Sensor Location: Unreliability Minimization

Minimize system unreliability

    Unreliability of fault with maximum unreliability value

Formulation II:

$$\min_{\forall j}\left[\max_{\forall i}\left\{ f_i\left(\prod_{j=1}^{n}(s_j)^{(b_{ij}x_j)} \right) \right\} \right]$$

subject to,

$$\sum_{j=1}^{n} c_j x_j \leq C^*$$

$$x_j \in Z^+, \ j = 1,...,n$$

where,

c_j=cost of sensor on variable j

C^*=total available cost

x_j=non-negative integer decision variables

Sensor Location: ILP Formulation

Equivalent standard mixed integer linear programming (MILP) formulation

Formulation III:

$$\min_{\forall j} Y$$

$$Y \geq \ln(f_i) + \sum_{j=1}^{n} b_{ij} x_j \ln(s_j), \quad i = 1,...,m$$

$$\sum_{j=1}^{n} c_j x_j \leq C^* \quad \text{Available Cost}$$

$$x_j \in Z^+, \; j = 1,...,n; \quad Y \in \Re^+$$

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Optimization Problem

- Features:
  - Multiple optimal solutions
- Incorporate additional objectives
  - Cost used
  - Robustness: sensitivity of solution to imprecisely knowing fault occurrence and sensor failure probabilities
- Lexicographic optimization
  - Objectives in decreasing priority
- Multiobjective optimization
  - Pareto front generation

Fault analysis in Plant wide model (WVU)

- Two faults simulated in sour syngas pipe.
  - Leakage after WGS reactor
  - Leakage before WGS reactor

- Dynamic simulation run for 6 hours.

- The valve flow coefficient is 10,000 ft$^{1.5}$ lb$^{0.5}$/hr.psi$^{0.5}$

- Valve ramped till 80% open in 0.3 hours

- Max leakage 0.12% of the total syngas flow rate.

Sampling Locations

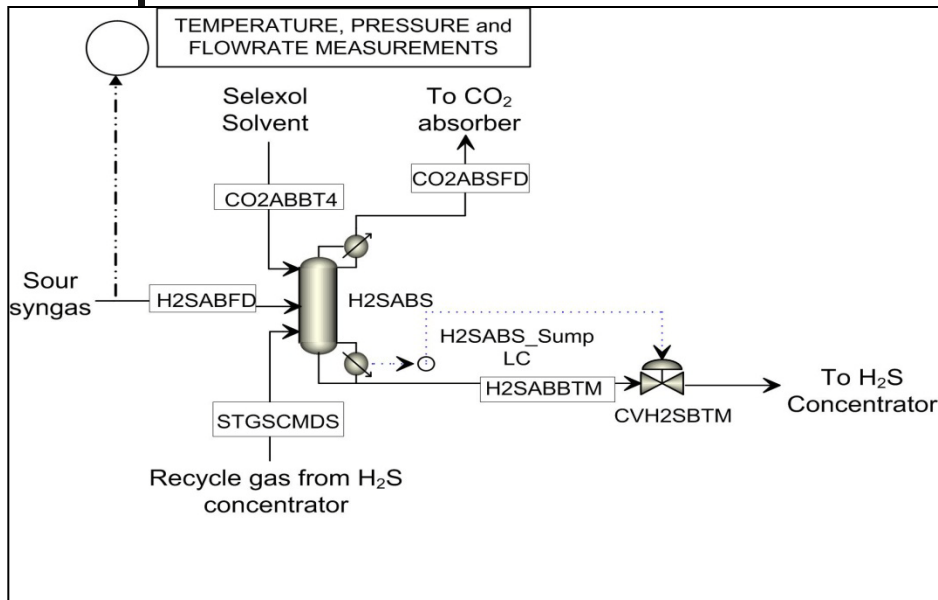**Figure 1**. Sampling location 1 for the simulated faults

Figure 2. Sampling location 2 for the simulated faults

- LOCATION 1
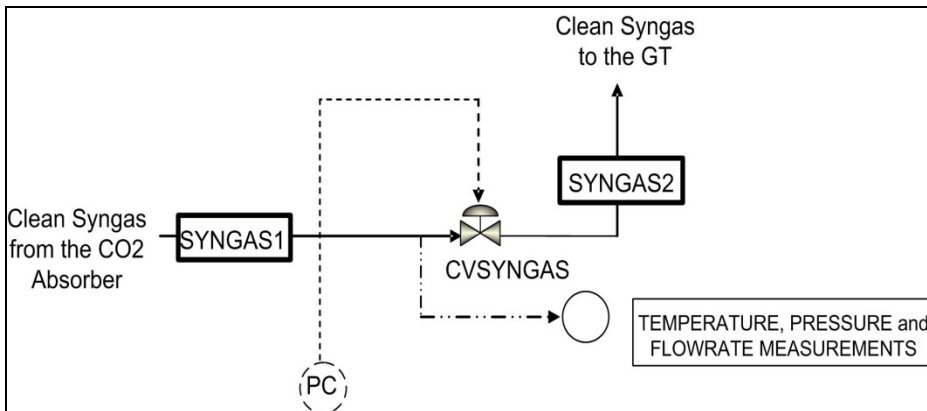 The main sour syngas stream at the inlet of the H_2S absorber in the acid gas removal (AGR) process.

- LOCATION 2
  Just before the control valve that regulates the flow of the clean syngas from the CO_2 absorber to the GT.

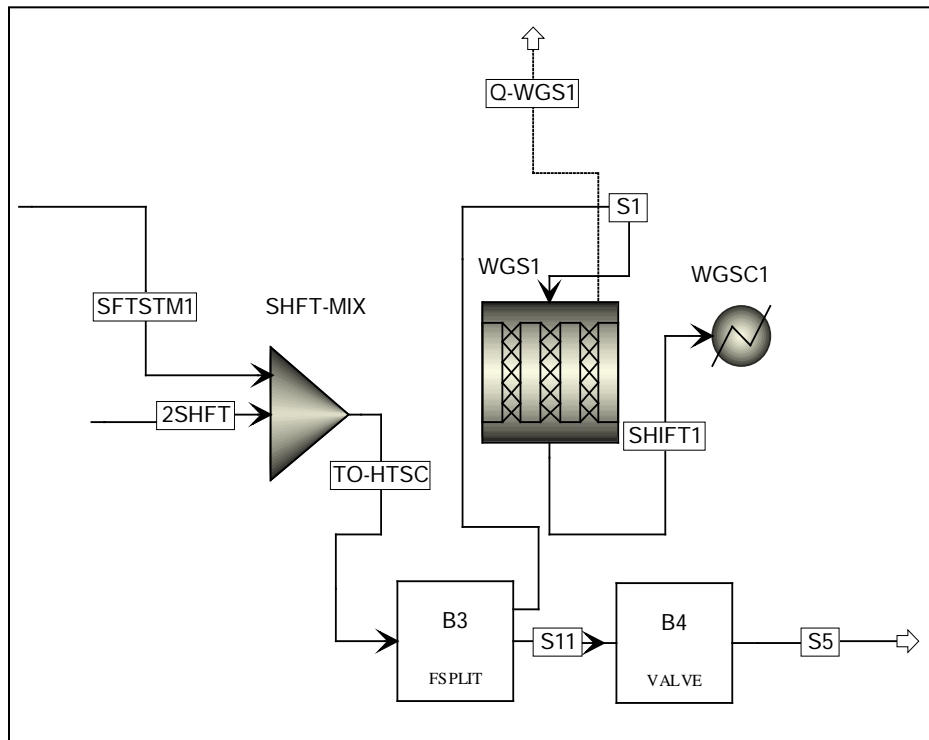# Leakage in sour syngas pipe before the WGS reactors

Figure 3. A section of the modified flowsheet to simulate the leakage in the sour syngas pipe before the WGS reactors

- The stream from the Mixer (SHFT-MIX) is directed to a splitter (B3).

- A split stream (S11) that represents the pipe leakage is sent to the Valve (B4).
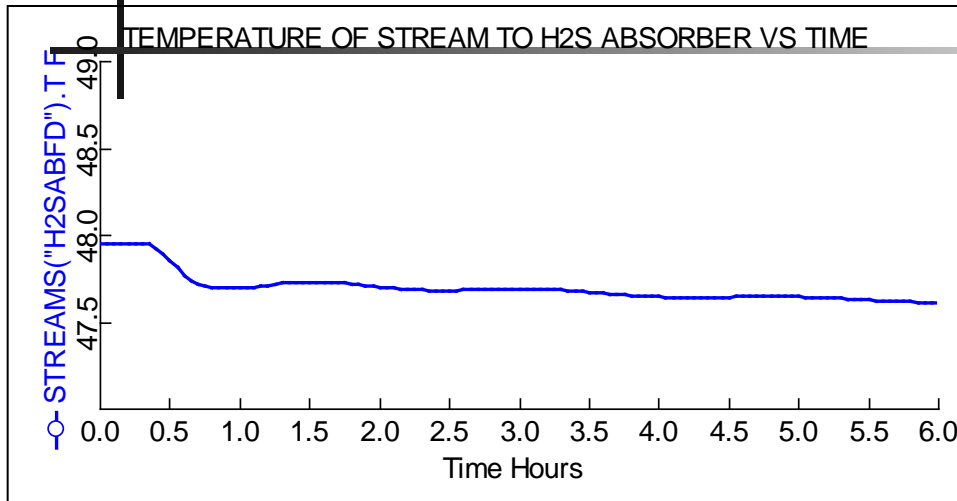
Results – Temperature profile change

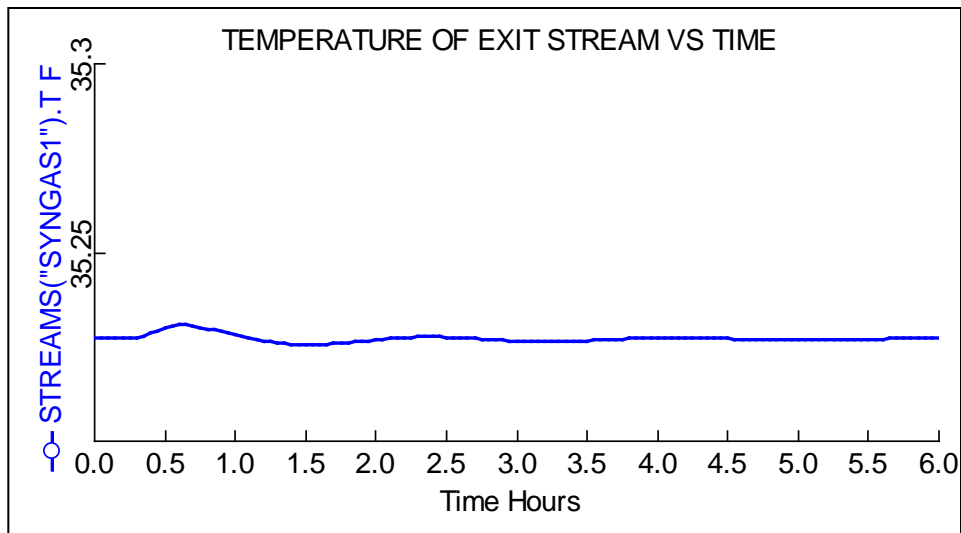**Figure 4** : Transient response in temperature in sampling location 1 due to Fault 1

Figure 5: Transient response in the temperature in sampling location 2 due to Fault 1

- Figure 4 shows that the settling time of temperature in sampling Location 1 is about an hour after the ramp change has been completed.
- The temperature decreases and then settles to a lower value than the previous steady state value.

- In location 2, as can be seen from Fig. 5, the temperature initially increases very little and then settles almost to the previous steady state value.
- The reason for initial increase in the temperature in Location 2 is the decrease in the inventory of the system due to the leakage.

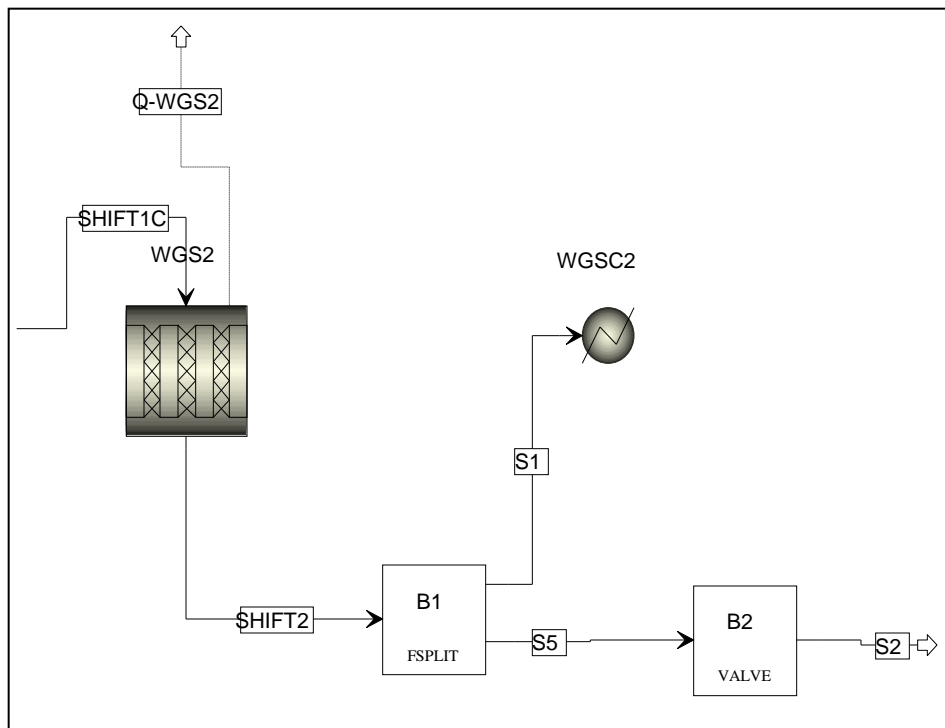# Leakage in the sour syngas pipe after the WGS reactors

Figure 6:   A section of the modified flowsheet to simulate the leakage in the sour syngas pipe after the WGS reactors.

- The leakage in the sour syngas pipe after the WGS reactors is diverted to a splitter (B1).

- A split stream (S5) that represents the pipe leakage is sent to the Valve (B2).

RESULTS – Temperature profile change

TEMPERATURE OF STREAM TO H2S ABSORBER VS TIME
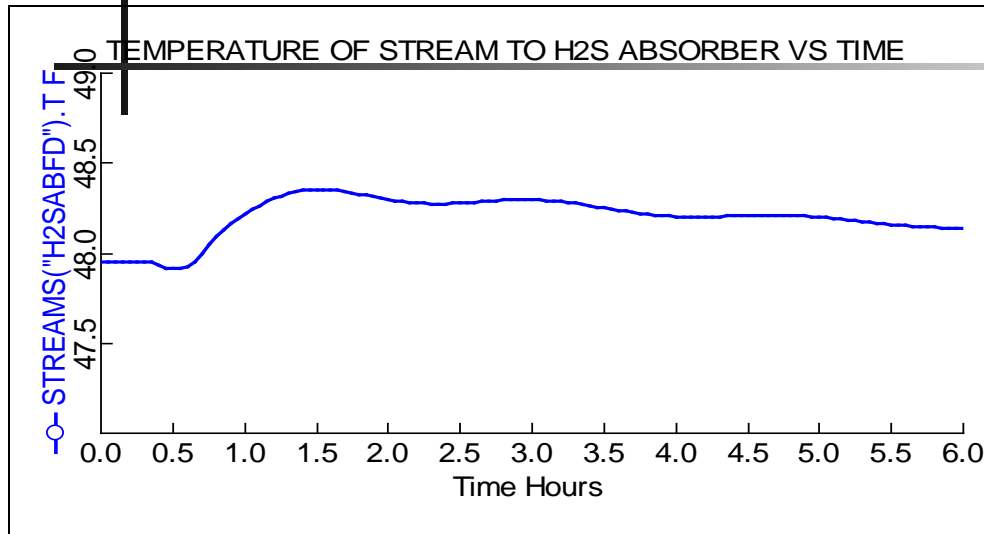
Figure 7: Transient response in temperature in sampling location 1 due to Fault 2

TEMPERATURE OF STREAM OF EXIT VS TIME
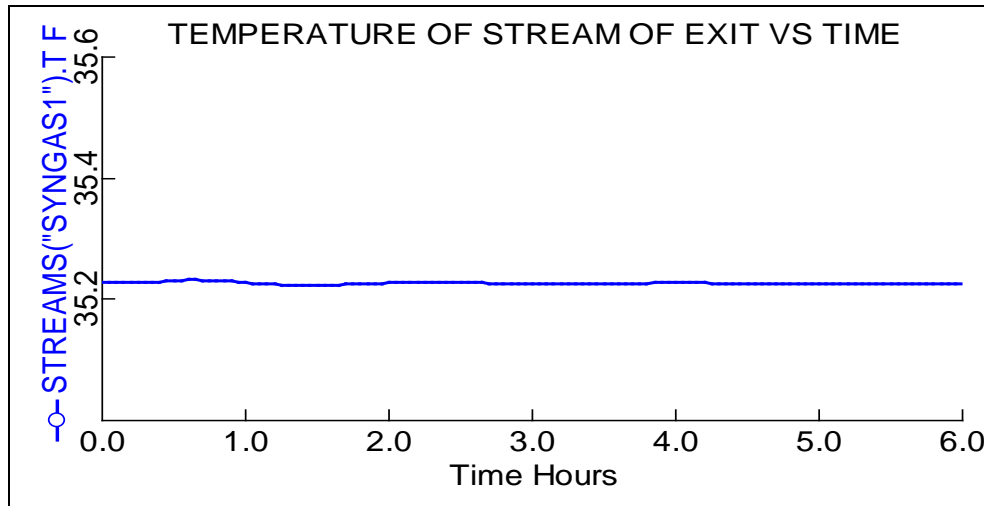
Figure 8: Transient response in the temperature in sampling location 2 due to Fault 2

- Shows that the temperature dynamics in sampling Location 1 due to Fault 2 is much different than the corresponding dynamics due to Fault 1.

- One of the interesting characteristics is the inverse response as the fault is simulated.

- Figure 8 shows that notable difference exists in the temperature transients between the two sampling locations similar to Fault 1.

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DISTRIBUTED SENSOR PLACEMENT

WGSR Model - Assumptions

- 1-D Model, no radial diffusion
- Ideal gas equation, velocity is a function of inlet molar flow rate
- Pressure drop is dictated by friction factor (dominant term)
- Effectiveness factor for reaction kinetics, however all heat is assumed to be generated at the catalyst surface
- No heat loss
- Heat transfer coefficient calculated through empirical correlations

Modeling equations

- Gas phase species balance

$$\frac{\partial C_i}{\partial t} = -GR \frac{T_g}{P} \frac{\partial C_i}{\partial z} - C_i GR \left[\frac{1}{p} \frac{\partial T_g}{\partial z} - \frac{T_g}{P^2} \frac{\partial P}{\partial Z} \right] + r_i \rho_{cat} \frac{(1-\epsilon)}{\epsilon}$$

- Momentum balance equation

$$\frac{dP}{dz} = \frac{\rho_{avg} V^2}{D_{cat}} \frac{(1-\epsilon)}{\epsilon^3} \left(1.75 + \frac{150(1-\epsilon)}{Re} \right)$$

- Catalyst phase energy balance
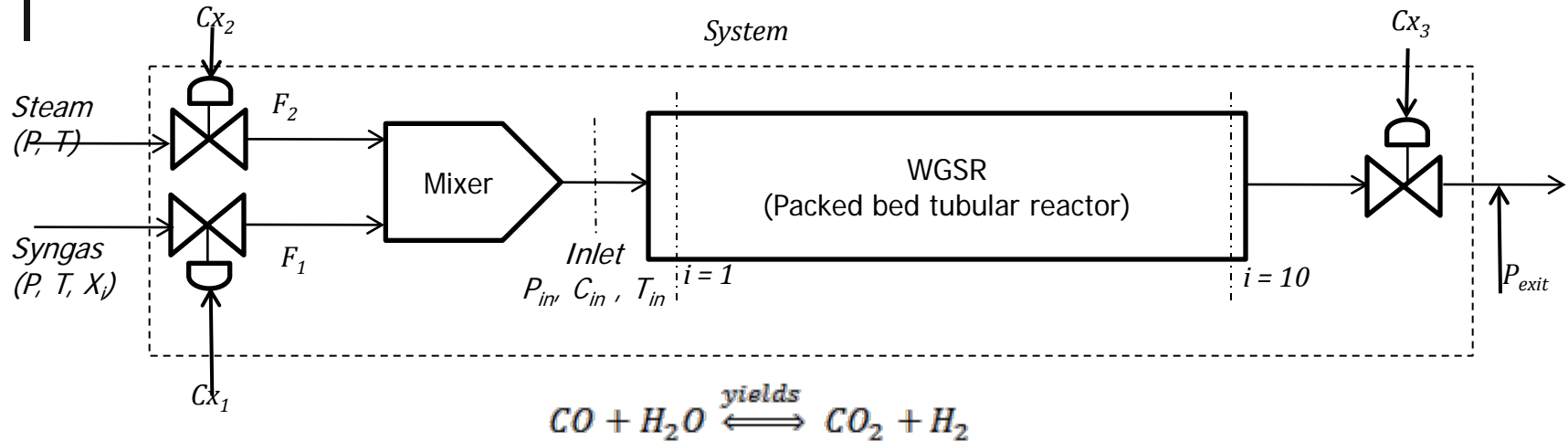
$$\rho C_{p,cat} \frac{\partial T_{cat}}{\partial t} = K \frac{\partial^2 T_{cat}}{\partial z^2} - h_f a_c \left(\frac{T_{cat} - T_g}{1-\epsilon} \right) + r_{co} \rho_{cat} \Delta H_R - \frac{Q_{loss}}{1-\epsilon}$$

- Gas phase energy balance

$$\rho_{g,mol} C_{p,mol} \frac{\partial T_g}{\partial t} = -C_p G \frac{\partial T_g}{\partial z} + \frac{h_f a_c (T_{cat} - T_g)}{\epsilon}$$

Water gas shift reactor

$$CO + H_2O \overset{yields}{\rightleftharpoons} CO_2 + H_2$$

Exogenous inputs

- Input Syngas (P, T, X_i)
- Input Steam (P, T)
- Valve opening (Cx_i)
- Exit pressure (P_{exit})

States of the system

Inlet:

P_{in}, C_{in} x 4, T_{in} ➔ 6 states

Reactor grids 1 to 10 :

P_i, C_i x 4, $T_{i, gas}$, $T_{i, catalyst}$ ➔ 70 states

Algebraic states

- **Total algebraic states of the system : 23**
  - Inlet concentration (C_{in}) x 4 components
  - Inlet pressure and temperature (P_{in} & T_{in})
  - Initial condition (1st grid)
    - T_{gas}, T_{cat}, C_1 x 4
  - Pressure (P_i) at all grid points
  - Boundary condition:
    - Temperature of catalyst (T_{cat})

Differential states

- Species concentration from grid 2-10
- Gas temperature from grids 2-10
- Catalyst temperature from grids 2-9

Total differential states: 53

Total states of the system: 76

Algebraic equations

- Valve equations:

$$F_1 = \alpha_1 C x_1 \left(\rho_{gas} \left(P_{syngas} - P_{in} \right) \right)^{\frac{1}{2}}$$

$$F_2 = \alpha_2 C x_2 \left(\rho_{steam} \left(P_{steam} - P_{in} \right) \right)^{\frac{1}{2}}$$

$$F_{in} = F_1 + F_2$$

- Enthalpy balance across the mixer (1 eqn):

$$F_{in} C_{p,avg} (T_{in}) - [F_{syngas} C_p(T) + F_{steam} C_p(T)] = 0$$

- Inlet concentration (4 eqns):

$$C_{in} = \frac{x_i P_{in}}{Z R T_{in}}$$

- Balance exit pressure (1 eqn)

$$P_{out} = \frac{1}{\rho_{avg}} \left(\frac{Flow_{out}}{\alpha_3 C x_3} \right)^2 + P_{exit}$$

$$P_{10} - P_{out} = 0$$

Algebraic equations continued

- **Initial conditions (7 eqns):**

    $C_1 - C_{in} = 0$ x 4

    $T_{g,1} - T_{in} = 0$

    $T_{cat,1} - T_{in} = 0$

    $P_1 - P_0 = 0$

- **Boundary conditions (1 eqn):**

    $T_{cat,\,10} - T_{cat,\,9} = 0$

- **Momentum balance equation (grids 2:10, 9 eqns)**

    Total equations = 23

Discretized differential equations

- Grids i = 2 to 10

- Species balance (9x4) = 36 eqns

- Discretized species (i^{th}) balance:

$$\frac{\partial C_j^i}{\partial t} = -\frac{GRZT_j}{P_j}\left(\frac{C_j^i - C_{j-1}^i}{\Delta Z}\right) - C_j^i GRZ \left\{\frac{1}{P_j}\left(\frac{T_j - T_{j-1}}{\Delta Z}\right)\right\} - \frac{T_j}{P_j^2}\frac{(P_j - P_{j-1})}{\Delta Z} + r_i \rho_{cat}\frac{1-\epsilon}{\epsilon}$$

- Discretized gas phase energy balance (Grids 2:10, 9 eqns):

$$\frac{\partial T_g}{\partial t} = \frac{1}{\rho_{g,mol}\,C_{p,mol}}\left\{-C_p G \frac{\left(T_j^g - T_{j-1}^g\right)}{\Delta z} + \frac{h_f a_c\left(T_j^{cat} - T_j^g\right)}{\epsilon}\right\}$$

- Discretized catalyst phase energy balance (Grids 2:9, 8 eqns):

$$\frac{\partial T_{cat}}{\partial t} = \frac{1}{\rho C_{p,cat}}\left\{K\frac{T_{j+1} - 2T_j + T_{j-1}}{\Delta z^2} - h_f a_c\left(\frac{T_j^{cat} - T_j^g}{1-\epsilon}\right) + r_{co}\rho_{cat}\,\Delta H_R\right\}$$

Discretized differential equations continued

- Total differential equations: 53

- Therefore total equations : 76
  - 53, differential and 23, algebraic

- Hence the system becomes a DAE system

Status

- WGSR dynamic simulation model developed

- Through discretization a DAE model form has been generated that is amenable for application of state estimation algorithms

- A DAE estimator that was recently developed and published by our research group can be used with this model

State estimation for the WGSR system

- Let x – represent all the differential states and z represent the Algebraic states
- F has dimension of 53x1 and Υ is process noise

$$\dot{x} = \bar{F}(x, z) + \gamma$$

- G has dimension of 23x1

$$\bar{0} = \bar{G}(x, z)$$

- Measurement model (Y)

$$Y = H \begin{bmatrix} x \\ z \end{bmatrix} + \omega$$

Estimation Algorithm

- Linearize the process model to estimate the noise covariance matrix

$$\dot{x} = \frac{\partial \bar{F}}{\partial x} \Delta x + \frac{\partial \bar{F}}{\partial z} \Delta z \qquad A = \frac{\partial \bar{F}}{\partial x} \qquad C = \frac{\partial \bar{G}}{\partial x}$$

$$0 = \frac{\partial \bar{G}}{\partial x} \Delta x + \frac{\partial \bar{G}}{\partial z} \Delta z \qquad B = \frac{\partial \bar{F}}{\partial z} \qquad D = \frac{\partial \bar{G}}{\partial z}$$

- Augmenting differential and algebraic states:

$$\begin{bmatrix} \dot{x} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} A & B \\ -D^{-1}CA & -D^{-1}CB \end{bmatrix} \begin{bmatrix} x \\ z \end{bmatrix}$$

$$x = A^{aug} x^{aug} \qquad \phi = e^{A^{aug} \Delta t}$$

Estimation algorithm

- Predicted covariance matrix

$$P_{k+1|k}^{aug} = \phi \, P_{k|k}^{aug} \phi^T + \tau Q_{k+1|k} \tau^t$$

$$\tau = \begin{bmatrix} I \\ -D^{-1}C \end{bmatrix}$$

- Augmented kalman gain:

$$K_{k+1}^{aug} = P_{k+1|k}^{aug} H_{k+1}^{aug} \left(H_{k+1}^{aug} P_{k+1|k}^{aug} H_{k+1}^{aug,T} + R_{k+1} \right)^{-1}$$

$$\hat{x}_{k+1|k+1}^{aug} = \hat{x}_{k+1|k}^{aug} + K_{k+1}^{aug} (y_{k+1} - h(\hat{x}_{k+1|k}^{aug}))$$

Estimation Algorithm

- After obtaining the present values on the estimates the algebraic states are estimated using the original model

$$\bar{G}\left(\hat{x}^{aug}_{k+1|k+1}, \hat{z}_{k+1|k+1}\right) = 0$$

- Updated covariance matrix is calculated as follows:

$$P^{aug}_{k+1|k+1} = \left(I - K^{aug}_{k+1} H^{aug}_{k+1}\right) P^{aug}_{k+1|k}$$

Fault simulations

- Porosity of the bed $\rightarrow$ by modifying ε
- Catalyst deactivation $\rightarrow$ by changing the pre-exponential factor at specific location of the reactor
- Change in surface area of the catalyst leading to changes in the effectiveness factor

Identification of important faults in the gasifier and the gasifier island

- **Thermocouples**
  - Do not survive if inserted into the gasifier flow path.
  - If the end of the thermocouple is flushed or if it is slightly withdrawn, it will result in inaccurate reading.

- **Level transmitter failure**
  - In May 1998, makeup water valve remained shut due to this and the hot well system ran out of water.

- **Density meters**
  - Provide good indication of slurry concentration but need to be calibrated daily to maintain accuracy.

- **Syngas header pressure disturbance**
  - Adjusting slurry rate is required to control the syngas header pressure.

- **Gasifier temperature disturbance**
  - To control the gasifier temperature, oxygen to slurry ratios can be adjusting

Gasifier Model – Features and Assumptions (WVU)

- Single–stage, Downward-firing, oxygen-blown, slurry-fed, entrained-flow gasifier

- 1-D Model (mass, energy, momentum) including several heterogeneous and homogeneous chemical reactions

- Devolatilization and drying of slurry feed included

- Detailed radiative heat transfer model, heat loss from gasifier wall to environment considered

- Heuristic recirculation model at the inlet of gasifier is developed and conservation equations modified appropriately
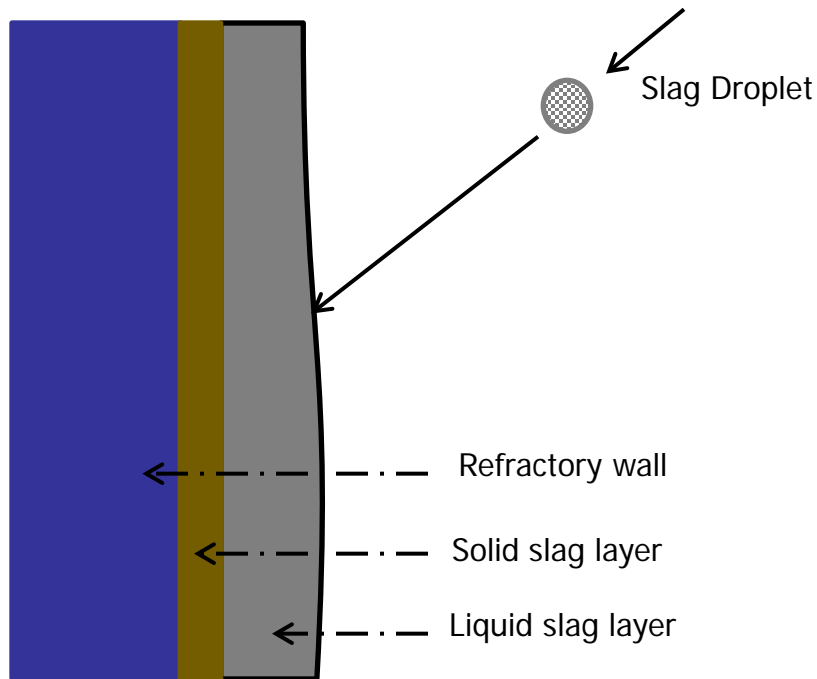
Figure 9: Layers of the wall.

- **Fault associated with gasifier that needs to be addressed**
  - Thinning of the refractory
  - Slag penetration inside the refractory

- **Amount of slag deposited at each level and thickness of slag layer on the wall should be known.**

- **Thus a slag model is essential to analyze and diagnose the gasifier faults.**

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Assumptions

- Particle shrinking model is assumed.

- The slag separating from the coal particle is considered to be in liquid phase as the temperature in the gasifier is higher than the melting point of the ash.

- Liquid phase has the same temperature as the solid phase.

- The coal particles are assumed to be uniformly distributed at each level of the gasifier.

- Slag is non wetting on the surface of graphite. The angle of contact is found to be well over 90 ° in such interactions. Due to the limited availability of data of contact angles on Illinois #6 coal, we have assumed that slag interacts with coal surface in a similar fashion.

- Single slag droplet separates from the coal particle. The non-wetting characteristic of the slag on the coal surface, along with the coal particle rotation allow for the ash to coalesce into a single particle.

- The capture efficiency of the slag droplet on the slag layer is assumed to be 1. All slag droplets that impact the slag layer will get captured.

Current work

- The mechanism for deposition of slag droplets on the wall is being considered.

- A model is being developed through which the velocity for each population size of slag droplets will be calculated and from this the slag layer thickness will be obtained.

- A similar model will be developed in order to find out the amount of char captured by the wall.

- A char capture efficiency will be calculated. Since the char is in solid phase, not all char impacting on the slag layer will get captured.

- A comparison between slag and char particle will be done once this model is available.

Next Steps (Year 2)

- Test the distributed sensor placement algorithm of the WGSR model

- Test the system level sensor placement on the identified smaller process

- Complete gasifier model enhancements

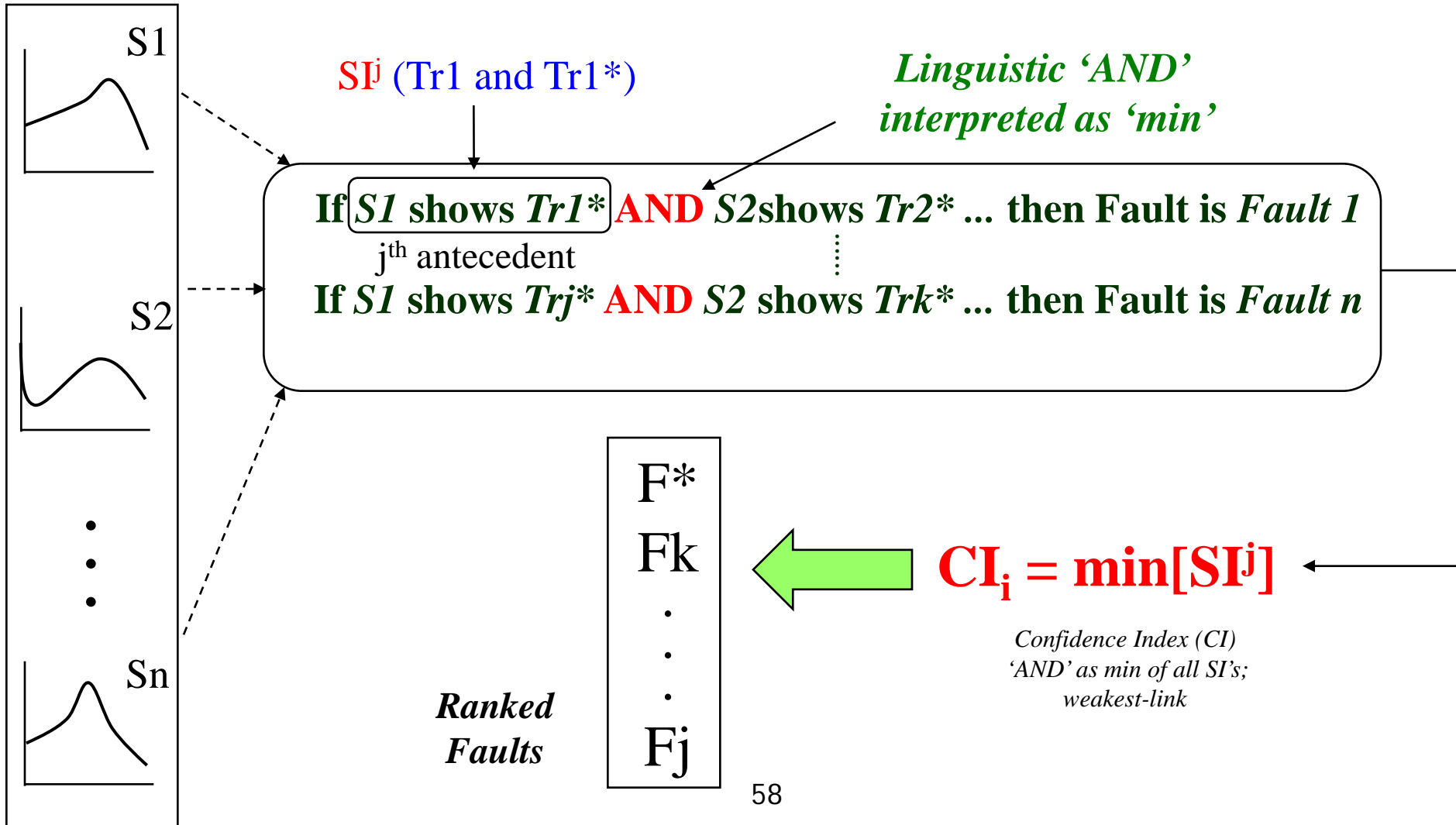- Test the distributed sensor placement on the gasifier model

Summary

- **Plant-wide sensor placement**
  - A Test-bed identified
  - Algorithm development in progress
  - Preliminary fault sets generated using the directed graph approach
- **Distributed sensor placement**
  - Water gas shift reactor model completed
  - Gasifier model being enhanced
  - Algorithm development in progress

Summary Continued – Diagnostic system based on trends in the chosen sensors

Sensor Trends   ## Knowledge-Base

SI^j (Tr1 and Tr1*)

Linguistic 'AND' interpreted as 'min'

If **S1** shows **Tr1*** **AND** **S2** shows **Tr2*** ... then Fault is **Fault 1**

j^{th} antecedent

If **S1** shows **Trj*** **AND** **S2** shows **Trk*** ... then Fault is **Fault n**

F*
Fk
.
.
.
Fj

Ranked Faults

$$CI_i = min[SI^j]$$

Confidence Index (CI) 'AND' as min of all SI's; weakest-link

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Summary continued

- Overall Vision

    - Development of a sensor placement system (software) for fault diagnosis and condition monitoring with a special focus on energy systems

    - Integrate sensor placement ideas with actuator selection/control structure selection

    - Integrated sensor network design algorithms that include data reconciliation, diagnostic and plant-wide control objectives that are rationalized through some common objective such as a monetized value and/or plant availability

Contact Info:

Raghunathan Rengaswamy

Professor, Department of Chemical Engineering

Co-Director Process Control and Optimization Consortium

Texas Tech University, Lubbock, Texas, USA

E-mail: raghu.rengasamy@ttu.edu

Phone: 806-742-3884

THANK YOU – QUESTIONS, COMMENTS ?