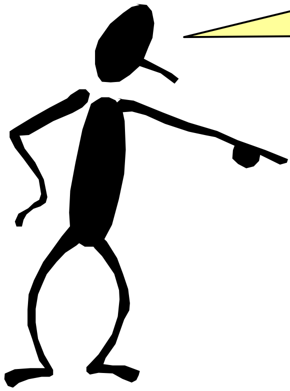
CHAPTER 17: Inferential Control



When I complete this chapter, I want to be able to do the following.

- **Identify key aspects of conventional and inferential sensors**
- **Determine good applications of inferential sensors**
- **Determine how to evaluate potential inferential sensors**

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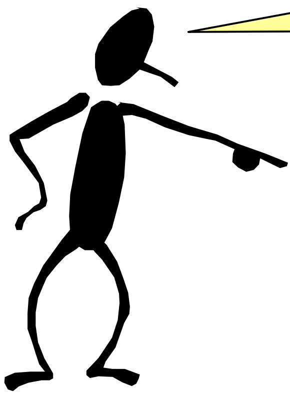


Outline of the lesson.

- Conventional and inferential sensors
- An example for a flash process
- Inferential design criteria
- Distillation example
- Reactor example
- Special considerations for dynamics

CHAPTER 17: Inferential Control

BASICS OF INFERENTIAL CONTROL

C ALL SENSORS ARE IN SOME SENSE INFERENTIAL

- ORIFICE ΔP FOR FLOW
- THERMOCOUPLE m Volt FOR TEMPERATURE

C CONVENTIONAL SENSORS MEASURE "TRUE" PROCESS VARIABLE

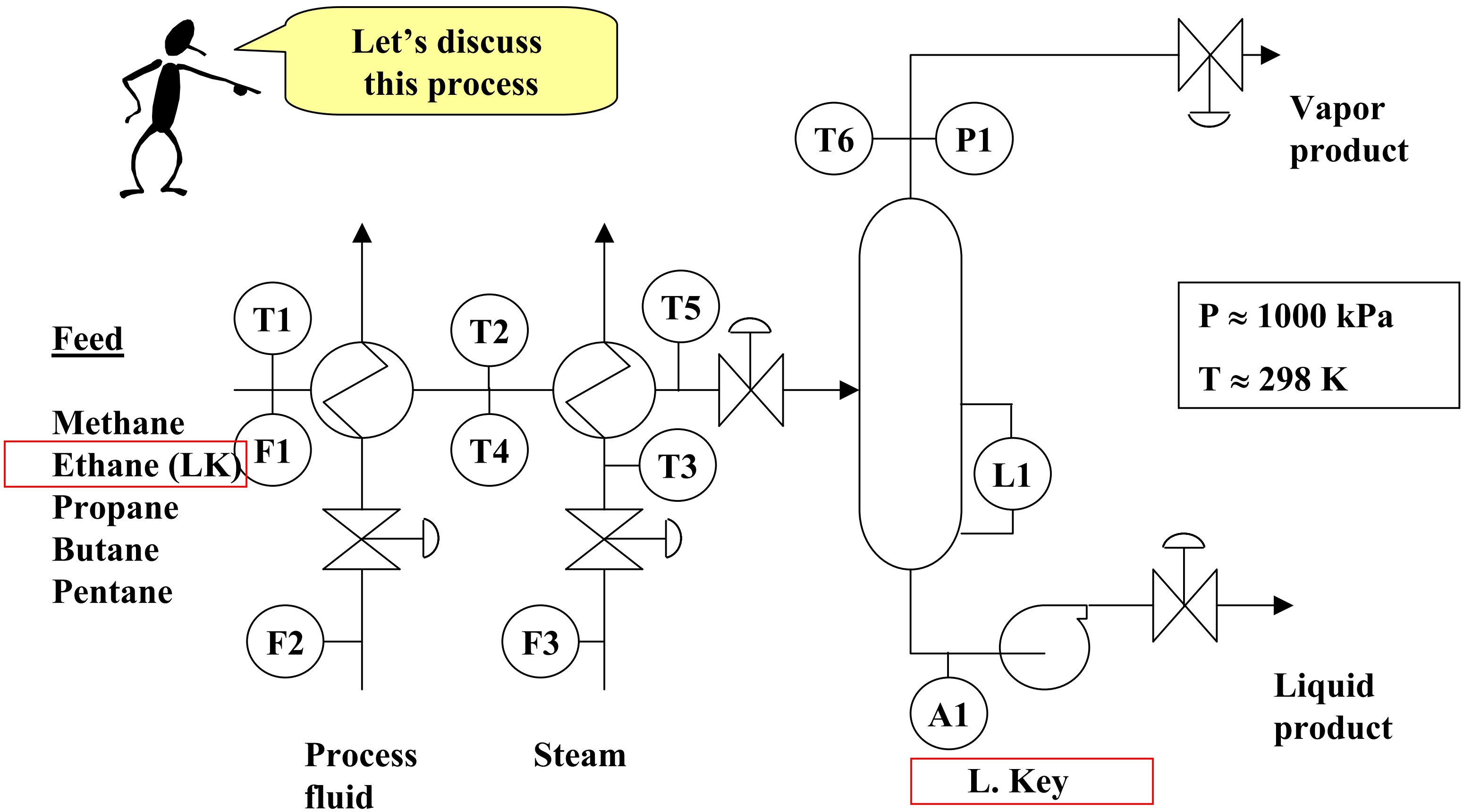
- REASONABLE ACCURACY & REPRODUCIBILITY
- LARGE RANGE W/ O CORRECTION
- NOT PROCESS SPECIFIC

C INFERENTIAL SENSORS

- PROCESS SPECIFIC
- LIMITED RANGE
- USUALLY PROVIDED POORER ACCURACY
- INFERENTIAL ADVANTAGES: FASTER RESPONSE, LOWER COST

EXAMPLE: FLASH DRUM

true variable	= x_e =	liquid composition of ethane to be controlled at 10%"2.0%
inferential variable =	T =	temperature
manipulated variable	=	heating medium flow
disturbance	=	feed composition (as subsequently defined)
inferential relationship :		$x_e = \alpha T + \beta$



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INFERENTIAL VARIABLES FOR CONTROL

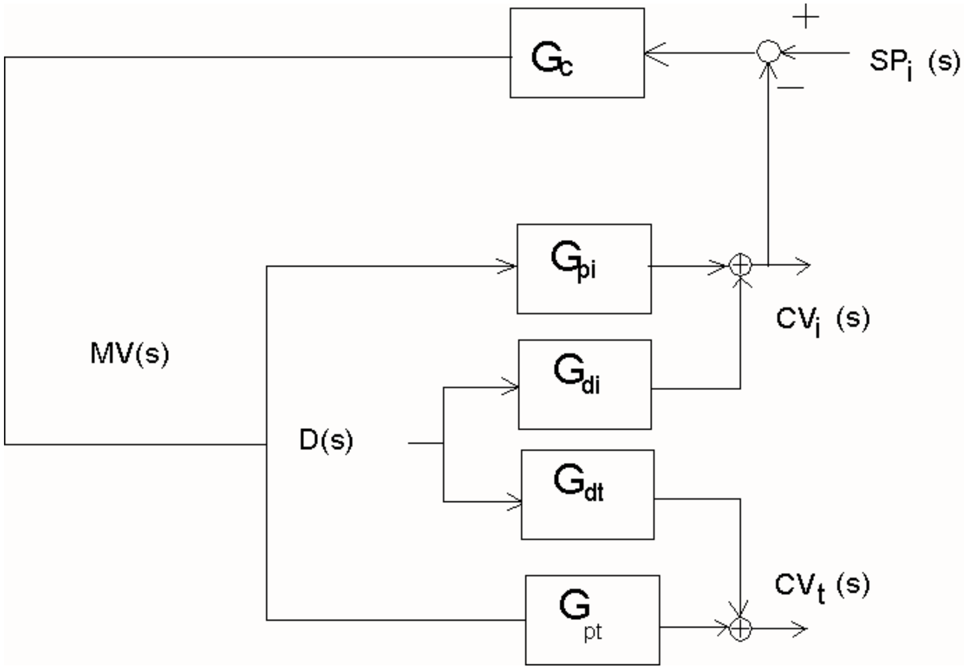
- CV_t = "TRUE" CONTROLLED VARIABLE

  CV_i = INFERENTIAL VARIABLE

- CONTROLLING CV_i TO ITS SET POINT DOES NOT GUARANTEE ZERO OFFSET FOR CV_t

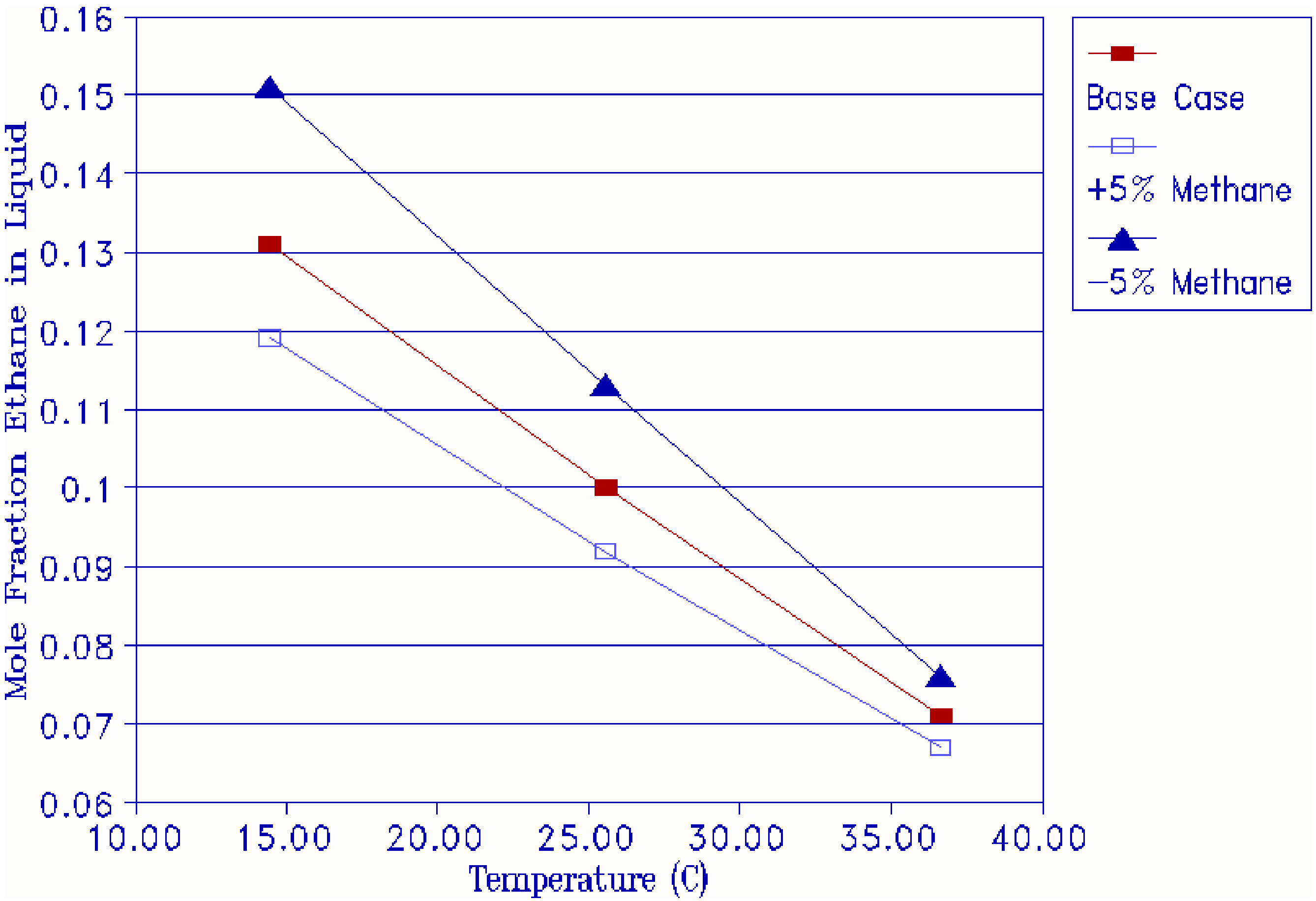
- WHAT CONDITION RESULTS IN ZERO OFFSET FOR CV_t?

- WHAT CONTROL ENHANCEMENT WOULD YIELD ZERO OFFSET?



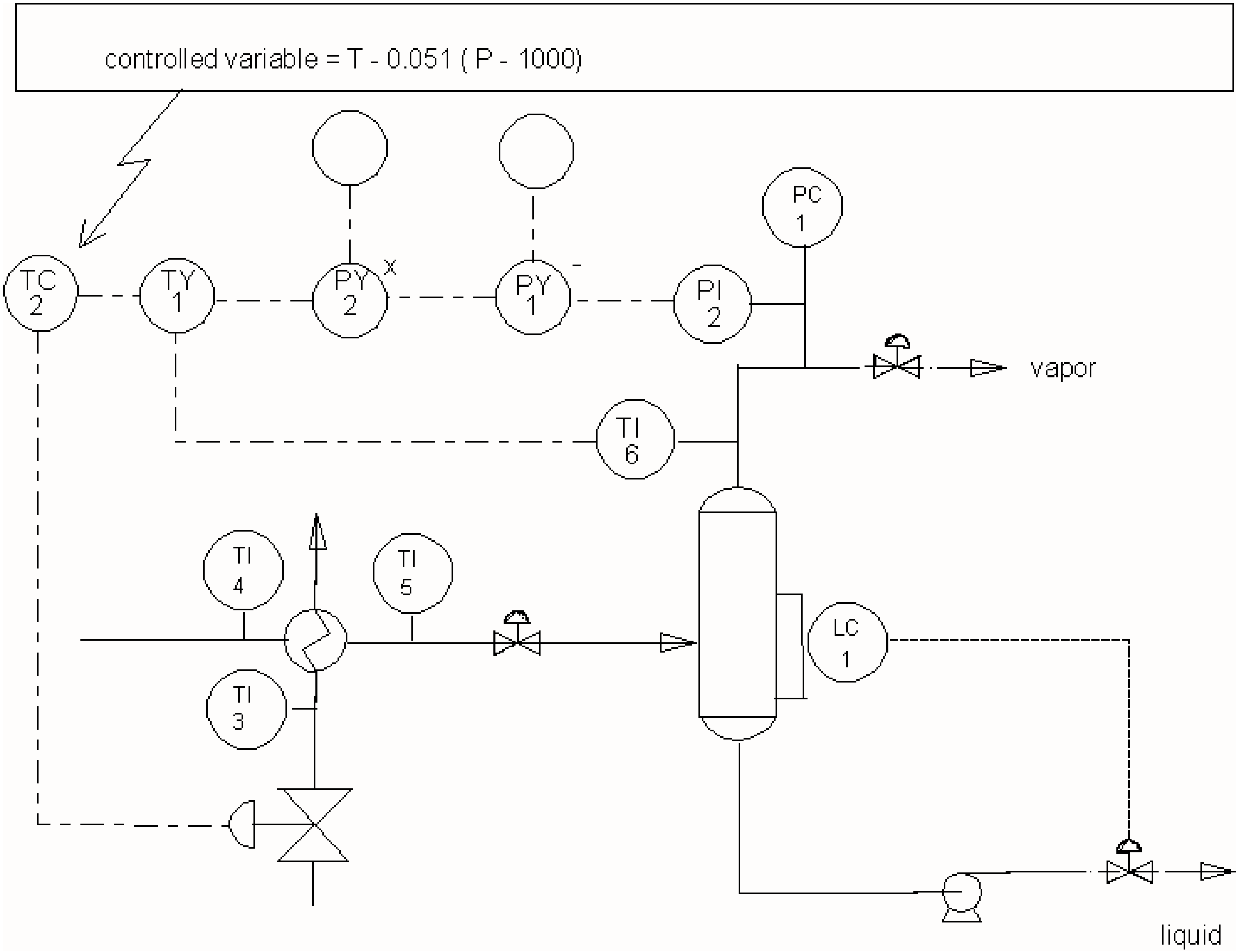
STEADY-STATE EVALUATION OF INFERENTIAL VARIABLE

- C CAN THE COMPOSITION BE MAINTAINED " 2% ?
- C ASSUME TEMPERATURE CONTROL IS "0.50 EC



The relationship between the flash temperature and the concentration of ethane in the liquid at the base case pressure (1000 kPa). Changes in methane are compensated by changes in butane of equal magnitude and opposite sign.

Inferential variable when pressure changes



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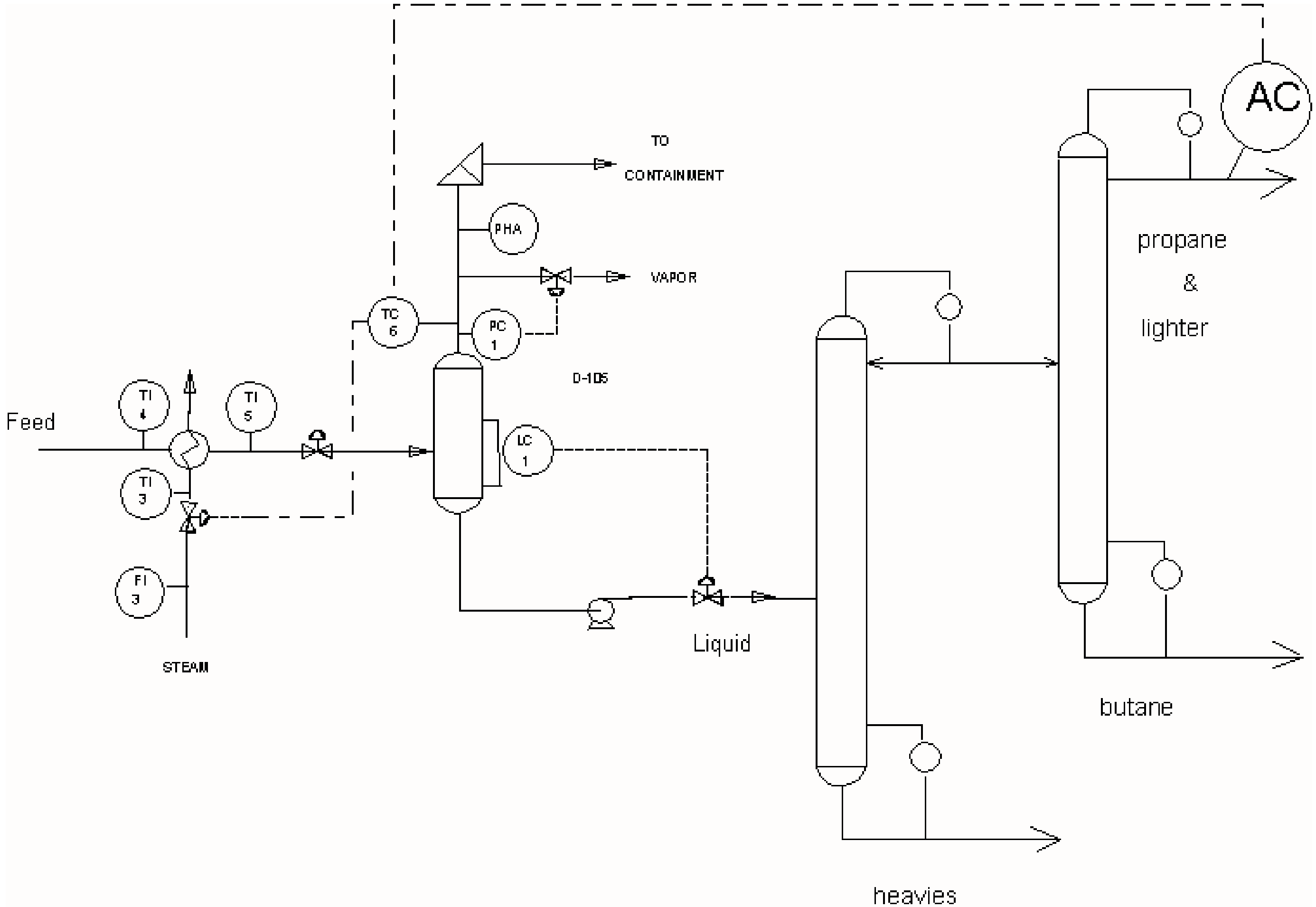
INFERENTIAL CONTROL WITH CASCADE RESET

- FAST INFERENTIAL, SLOWER PRIMARY
- ONE EXPENSIVE ANALYZER MEASURES TWO KEY VARIABLES



INFERENTIAL CONTROL DESIGN CRITERIA

Table 17-2. Design Criteria For Inferential Control

I. NECESSARY SITUATION

Measurement of the true controlled variable not available in a timely manner

A) Not measured: on-stream sensor not possible
B) Not measured: on-stream sensor too costly
C) Unfavorable feedback dynamics: sensor has poor dynamics, e.g., long dead time or analysis time, or is located far downstream

II. INFERENTIAL VARIABLE FEATURES

A) Good relationship to true controlled variable for changes in the potential manipulated variable
B) Relationship in (A) insensitive to changes in operating conditions, i.e., unmeasured disturbances, over their expected ranges
C) Favorable dynamics for use in feedback control

III. CORRECTION OF INFERENTIAL VARIABLE

A) By primary controller in automated cascade design
B) By plant operator manually based on periodic information
C) When inferential variable is corrected frequently, the sensor for the inferential variable must provide good reproducibility, not necessarily accuracy

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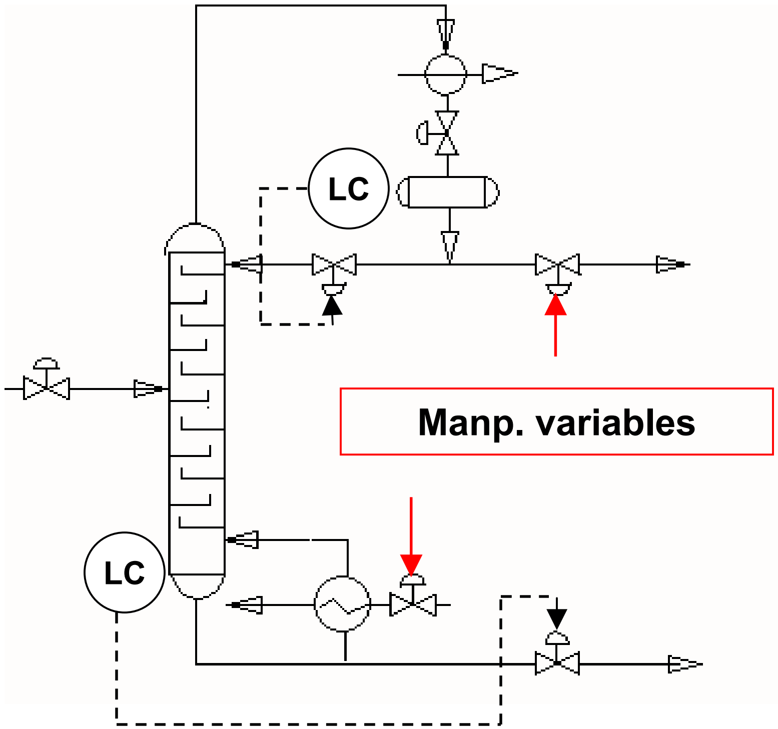
EXAMPLE: DISTILLATION TRAY TEMPERATURE

true variable	=	x_D	= heavy key in distillate = .01 mole fraction
inferential variable	=	T	= tray temperature
manipulated variable	=		distillate flow rate
disturbances	=		reboiler duty, feed composition
parameters	=		tray efficiency, thermodynamics

inferential relationship: $x_D = \alpha T + \beta$

Given the information in the temperature vs. tray no. figure, which is the best tray temperature?

Or, which temperature correlates best with x_d ?



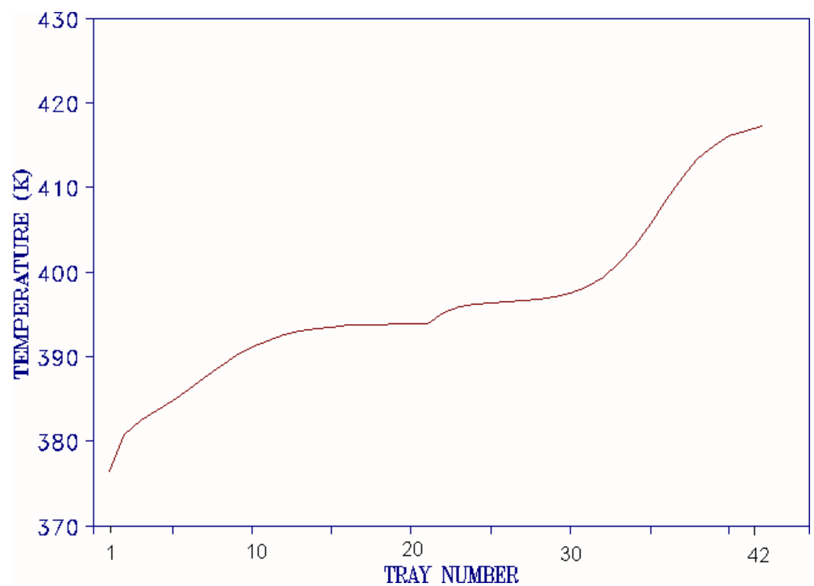
COLUMN DESIGN

COMPONENTS: BENZENE, TOLUENE, XYLENE

FEED COMPOSITION 10,45,45 MOLE %

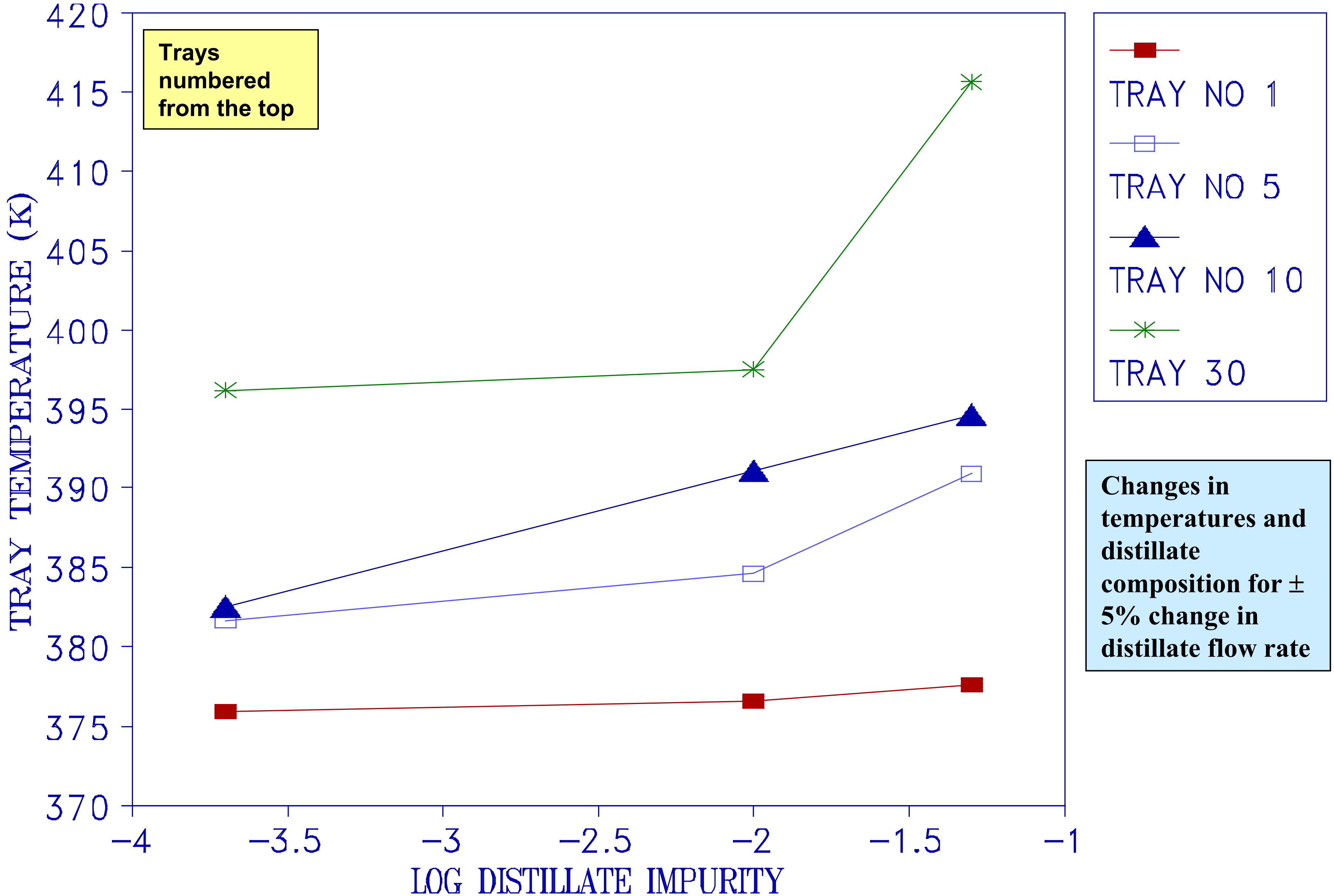
TOWER DESIGN:
42 IDEAL TRAYS
FEED AT TRAY 21 FROM TOP
pressure = 1000 kPa
DISTILLATE/FEED= 0.55
REFLUX/DISTILLATE= 1.01

BASE CASE COMPOSITIONS , MOLE %
distillate 1% xylene
bottoms 2.4% toluene

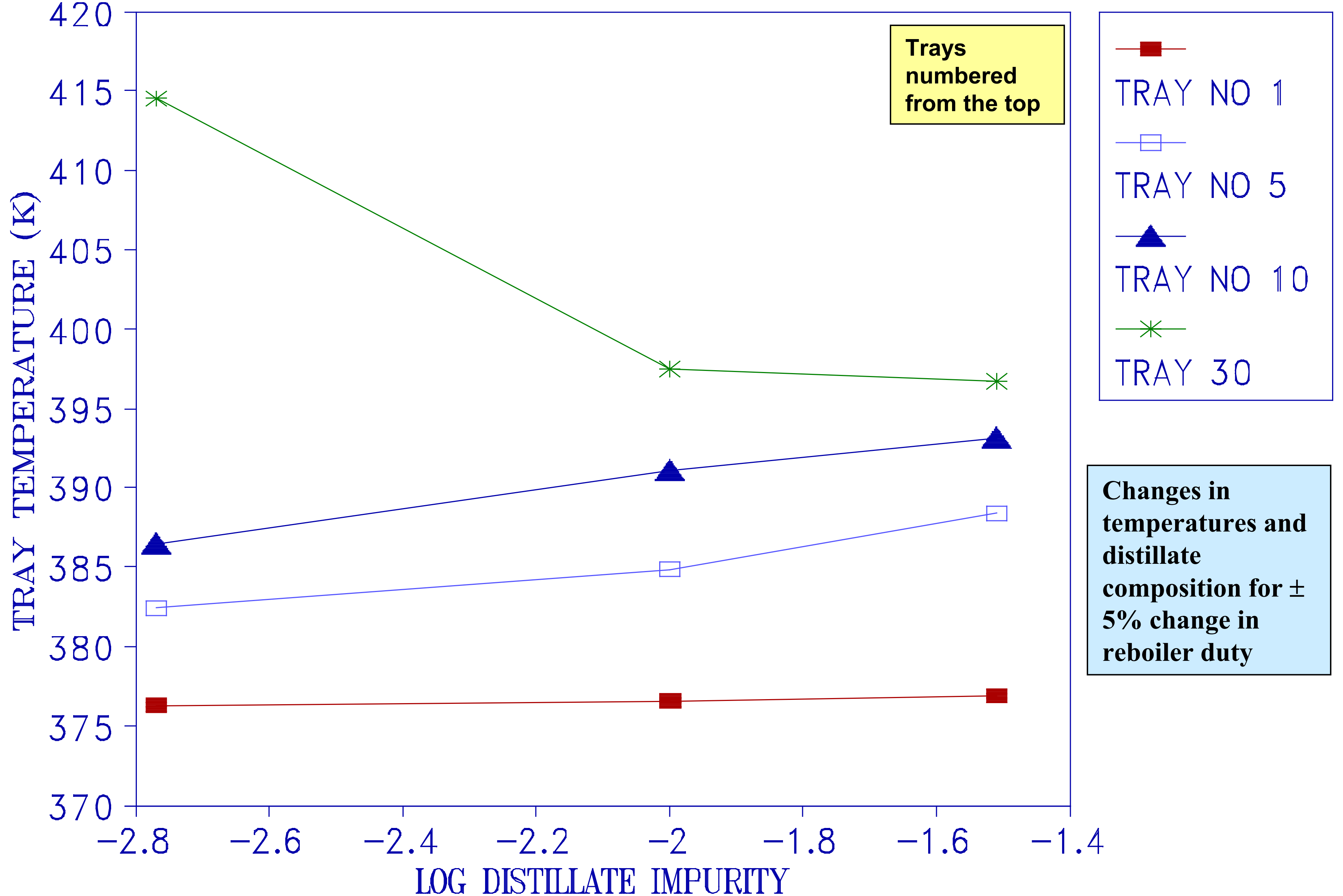


Trays numbered from the top

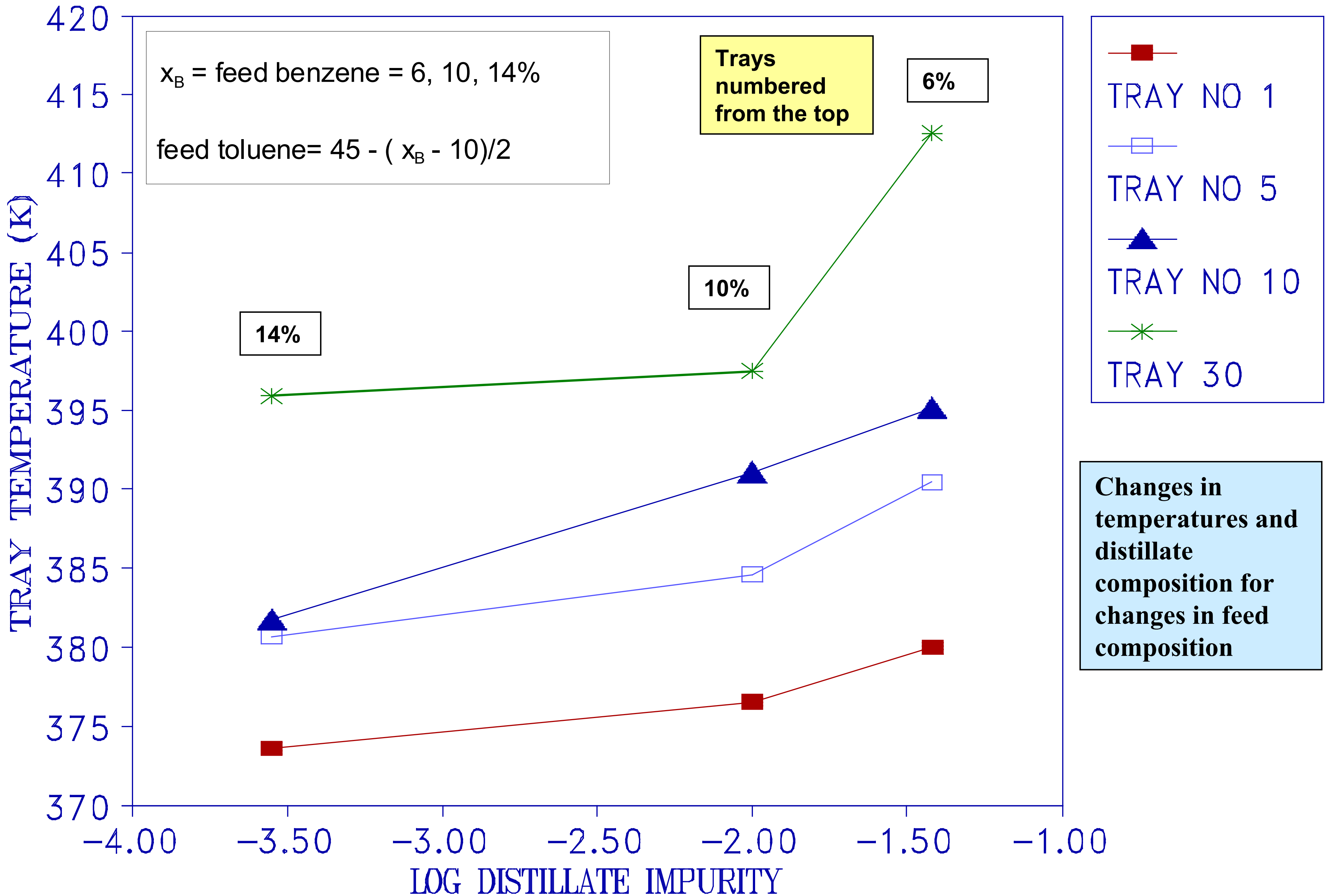
XD= fraction xylene



Changes in temperatures and distillate composition for ± 5% change in distillate flow rate



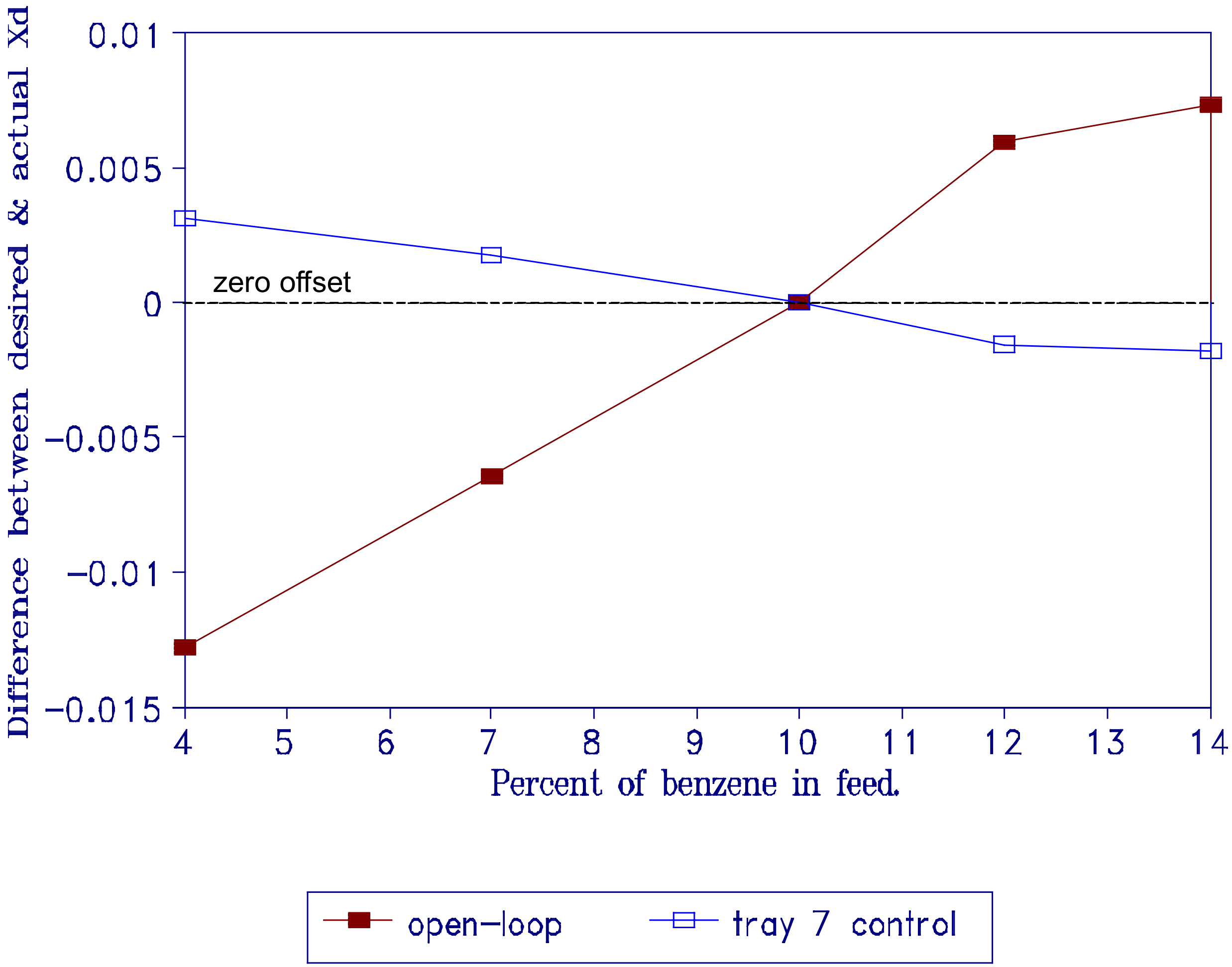
Trays numbered from the top
TRAY NO 1
TRAY NO 5
TRAY NO 10
TRAY 30
Changes in temperatures and distillate composition for ± 5% change in reboiler duty
TRAY TEMPERATURE (K)
LOG DISTILLATE IMPURITY
420
415
410
405
400
395
390
385
380
375
370
−2.8
−2.6
−2.4
−2.2
−2
−1.8
−1.6
−1.4



TRAY TEMPERATURE (K)
420
415
410
405
400
395
390
385
380
375
370
-4.00
-3.50
-3.00
-2.50
-2.00
-1.50
-1.00
LOG DISTILLATE IMPURITY
x_B = feed benzene = 6, 10, 14%
feed toluene= 45 - (x_B - 10)/2
Trays numbered from the top
6%
10%
14%
TRAY NO 1
TRAY NO 5
TRAY NO 10
TRAY 30
Changes in temperatures and distillate composition for changes in feed composition

IMPROVED PERFORMANCE VIA INFERENTIAL CONTROL

C MUCH REDUCED DEVIATION FROM DESIRED FOR FEED COMPOSITION DISTURBANCES



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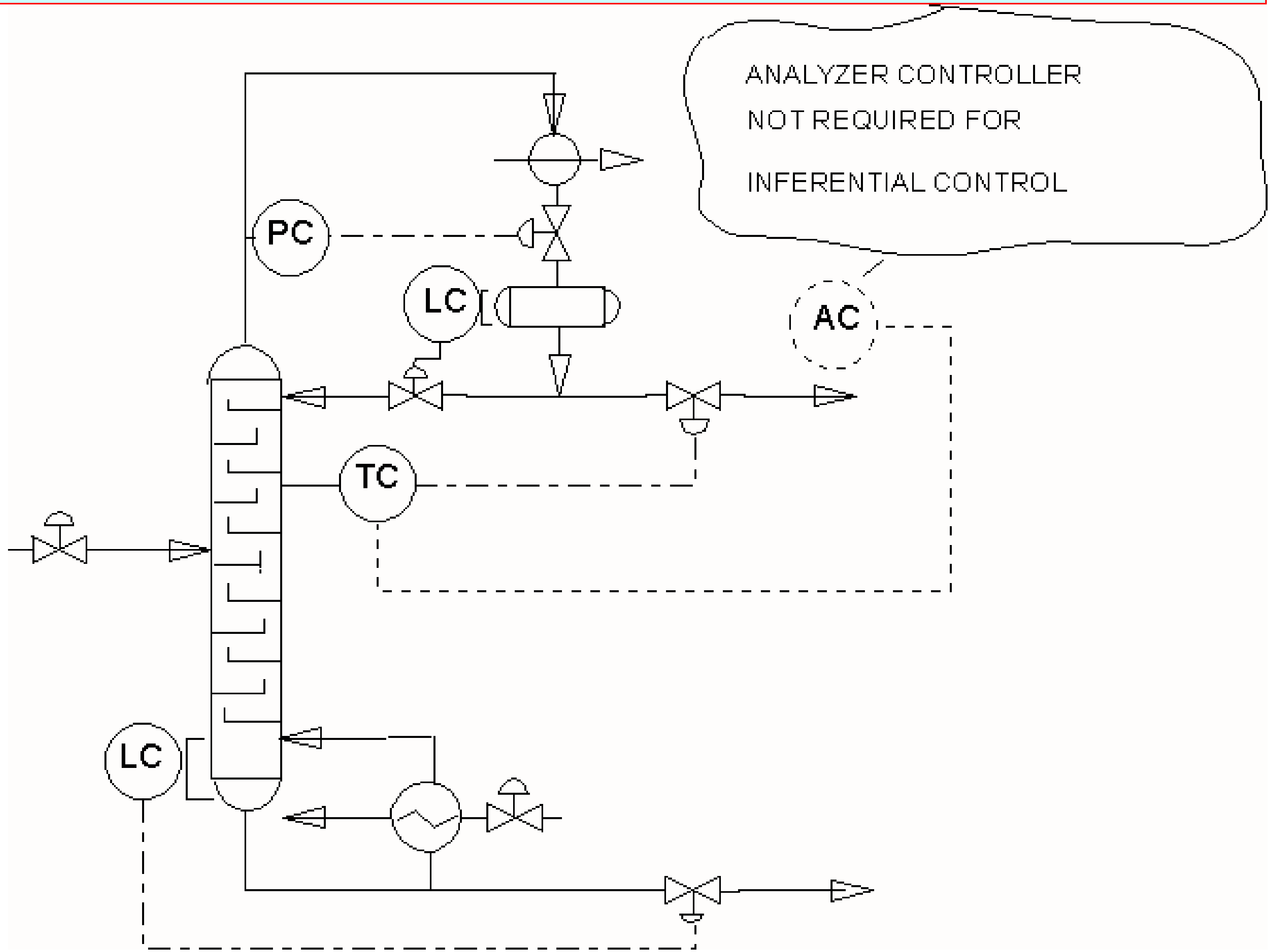

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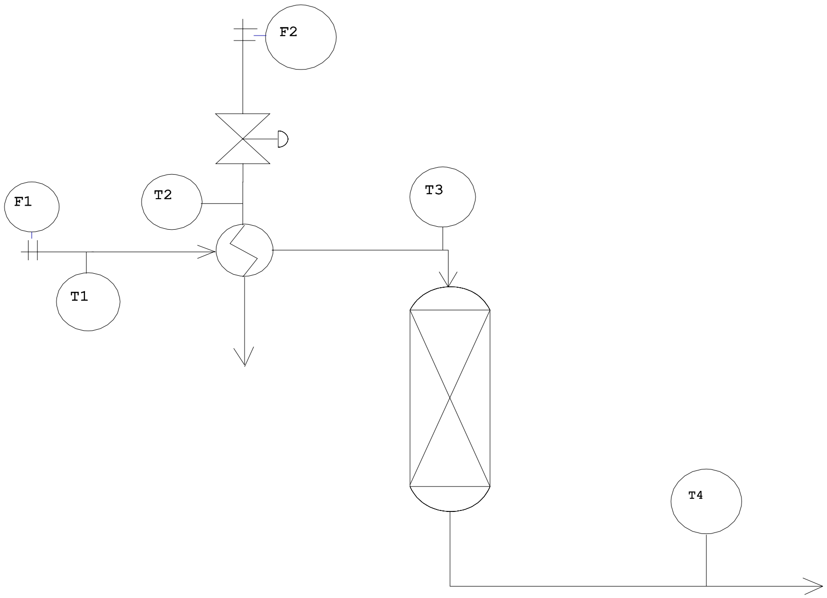
EXAMPLE: CHEMICAL REACTOR

C WHAT IS A GOOD INFERENTIAL VARIABLE?



$$A \rightarrow B$$

$$\Delta T = -\Delta H_{rxn} \frac{C_{Ain}}{\rho C_p} X_A = \frac{-\Delta H_{rxn}}{\rho C_P} \Delta C_A$$

$$\Delta T = T4 - T3$$

where

C_A = concentration of A, moles/volume
ρ = density, mass/volume
C_p = heat capacity, energy/(EC*mass)
ΔH_{rxn} = heat of reaction, energy/mole
X_A = fraction of feed reacted
= $(C_{Ain} - C_{Aout})/C_{Ain} = \Delta C_A/C_{Ain}$

REACTOR INFERENTIAL: DYNAMIC RESPONSE

C WOULD YOU EXPECT GOOD PERFORMANCE FROM THIS FEEDBACK SYSTEM?

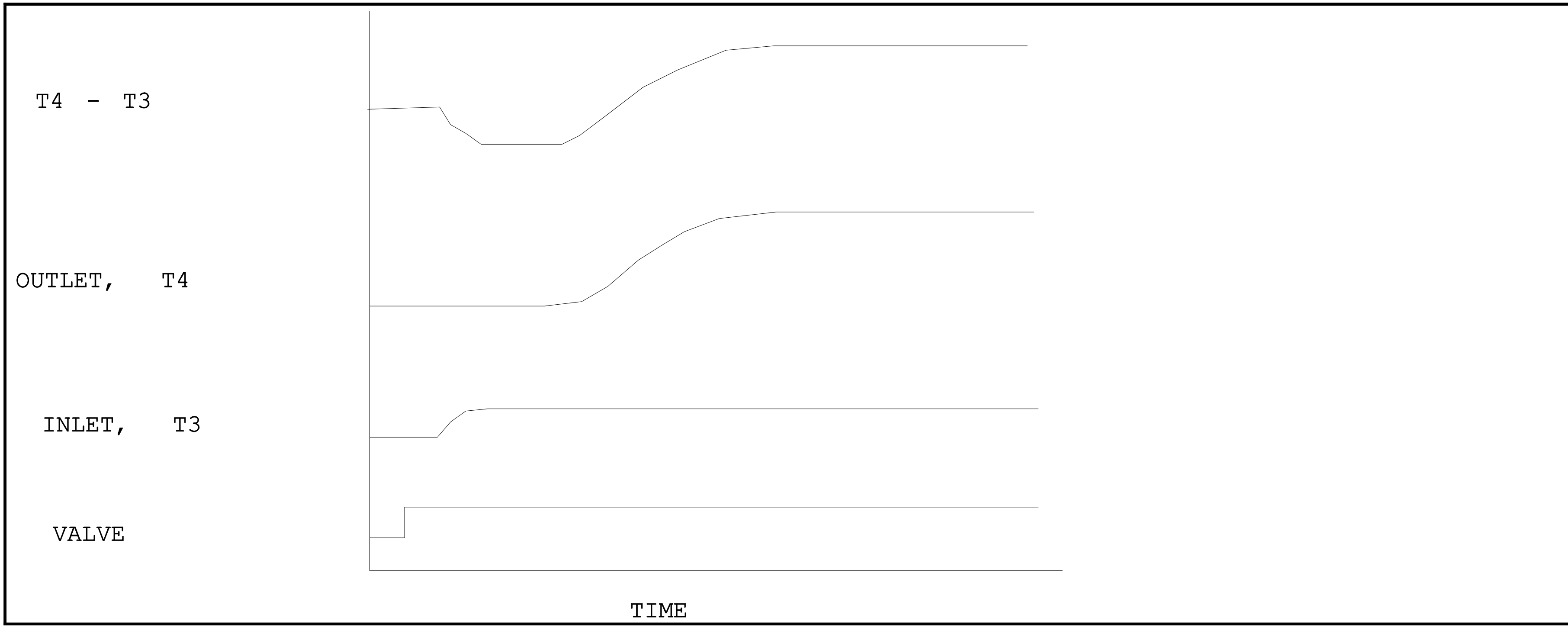


Figure 17-14. Plot of key variables for packed bed reactor inferential control. Note the significant inverse response of the instantaneous temperature difference.

C WHAT IF WE WANTED TO INFER B/ C, WHEN A6B and A6C ?