

Nuclear Magnetic Resonance Analysis Laboratory and On-line

Overview of the technology. Validation of the performance analyzer systems which employ multivariate models

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What is ^1H NMR Analysis?

- NMR = **N**uclear **M**agnetic **R**esonance
- “*Nuclear*” because NMR looks at the **nuclei** of molecules (protons-neutrons)
- More specific at their “**nuclear spin**”
- Some nuclei have a “**magnetic moment**” due to that spin (behave like a small magnet)
- Most important nuclei are ^1H , ^{13}C , ^{19}F and ^{31}P
- **^1H -NMR** is looking at ^1H -protons in molecules, excellent for hydrocarbon analysis



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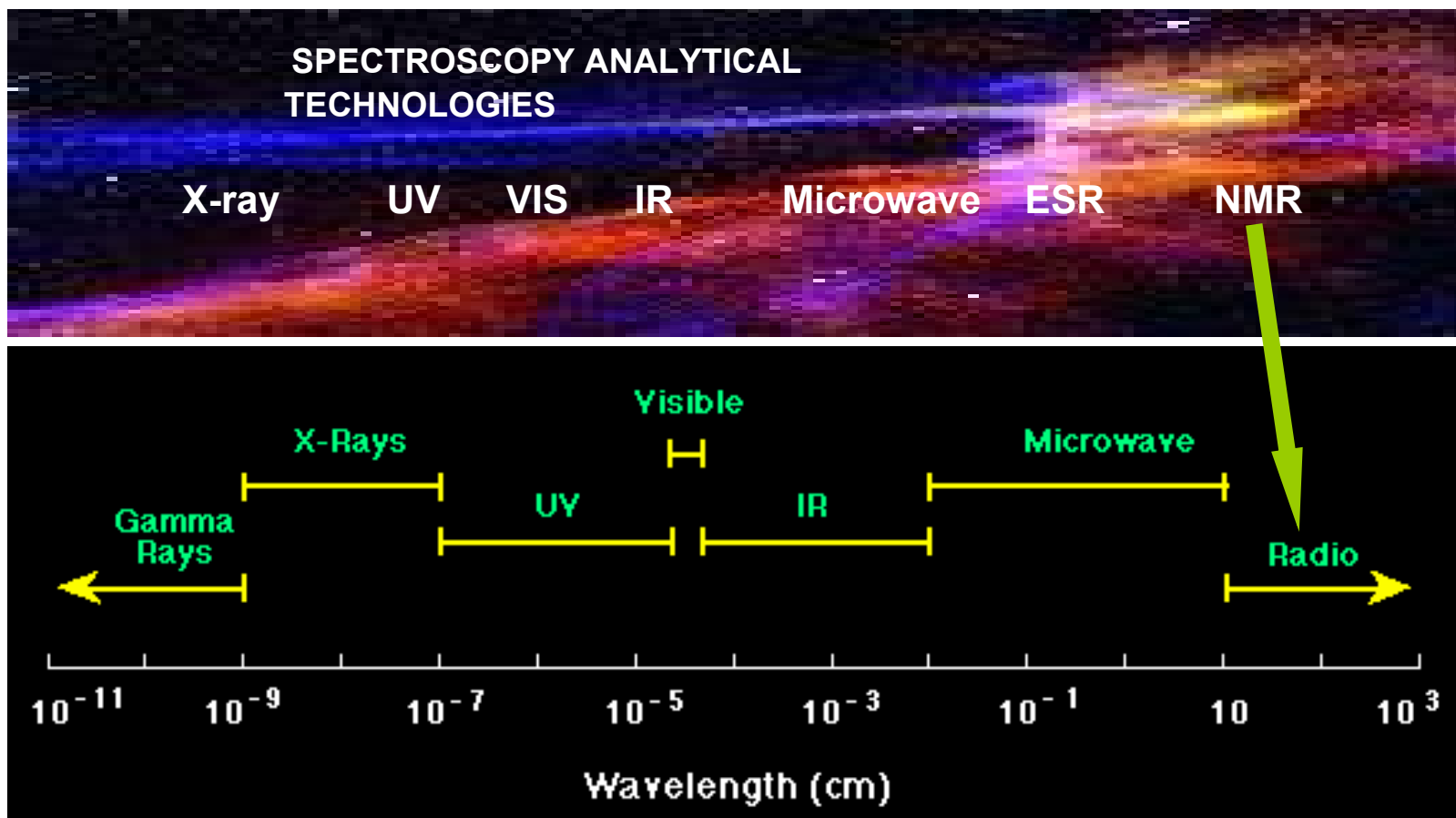
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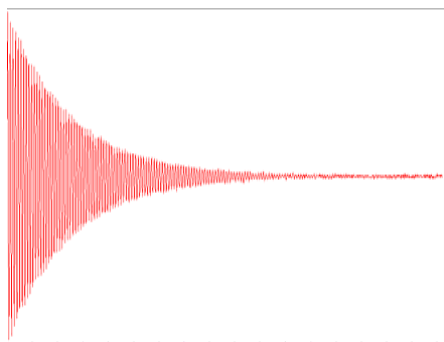
The Electromagnetic Spectrum



NMR spectroscopy uses radio-waves to interact with samples

From FID to results

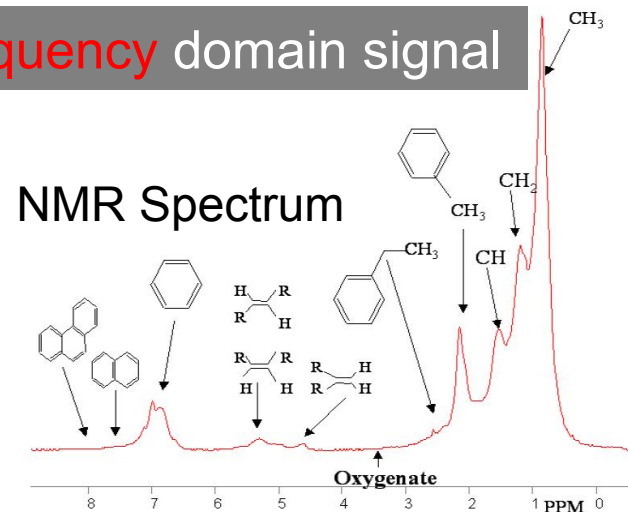
Time domain signal



Fast Fourier
transform

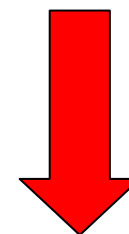


Frequency domain signal



H-Types Observed in a Gasoline ¹H NMR Spectrum

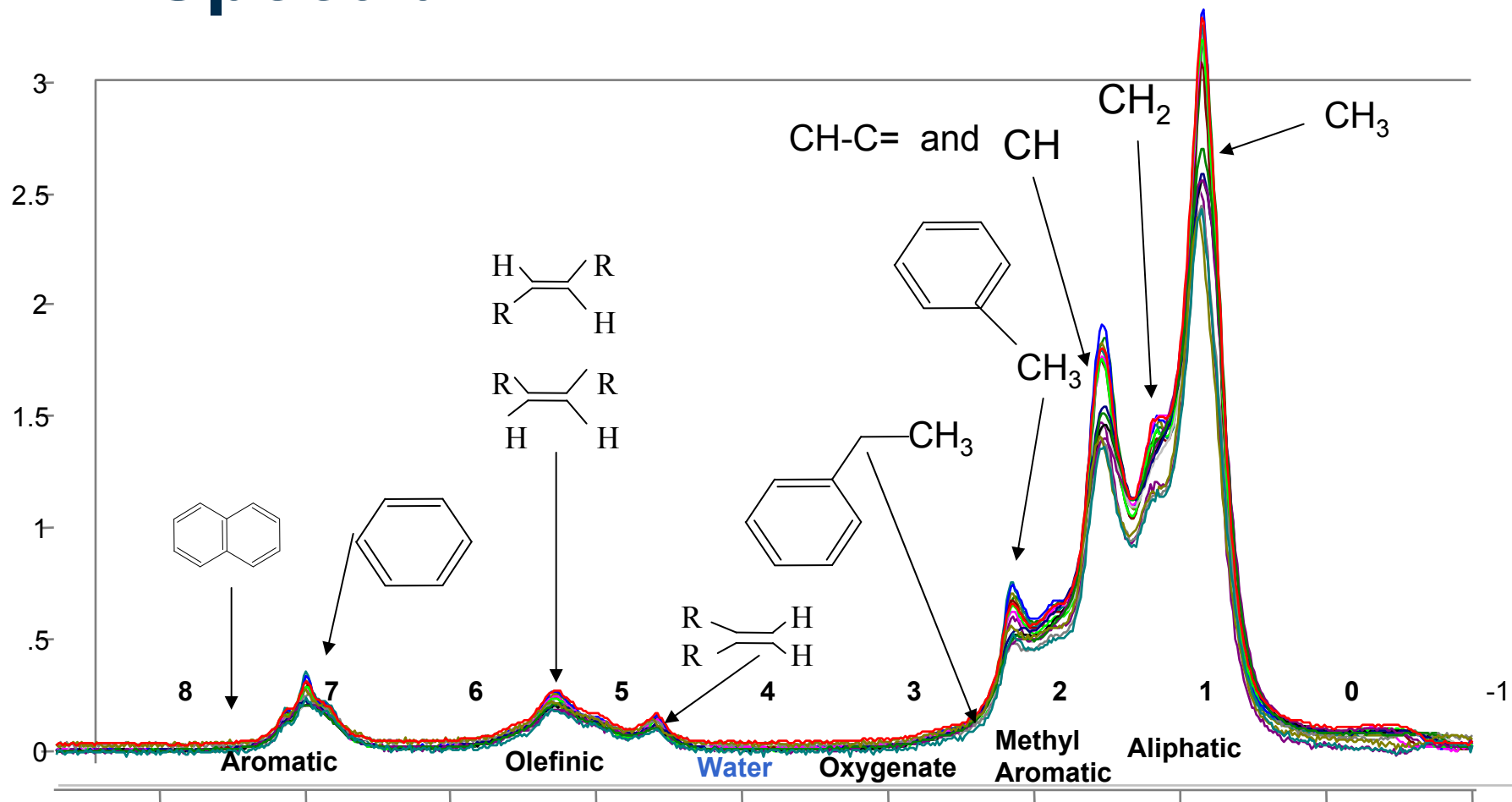
Chemometric
calibration models



Results

Free Induction Decay(FID)

NMR Spectrum



All functional groups are clearly resolved and have unique and documented location



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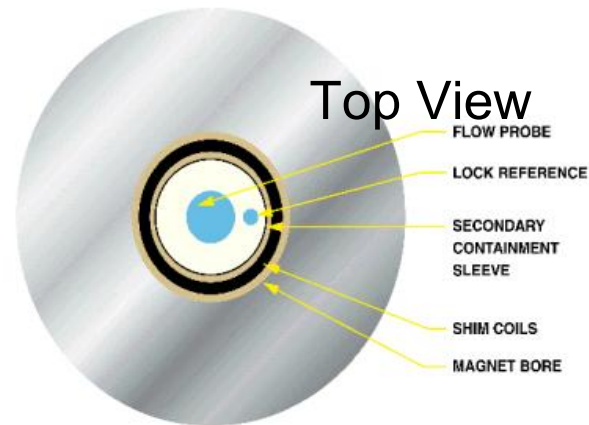
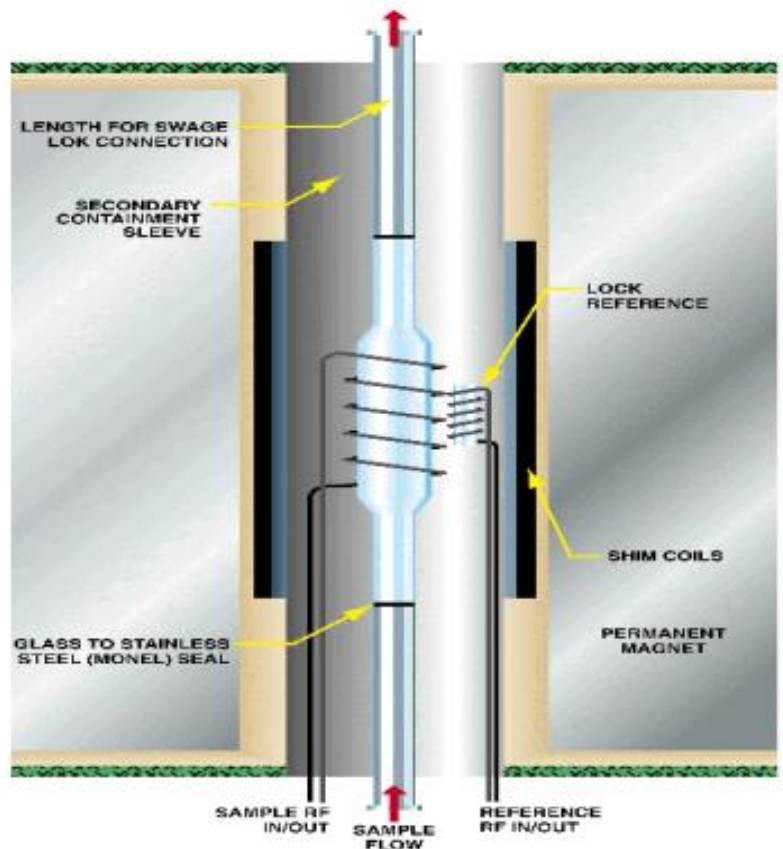


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Measurement in a NMR Process analyser



Magnet



A very important step is to clean the Probe. After at least three cycles of measuring, the Probe must be cleaned with kero so that the film of the heavy hydrocarbon is removed, because that interferes with radio frequency.

WHAT IS CHEMOMETRICS?

- *“Chemometrics is the science of relating measurements made on a chemical system or process to the state of the system via application of mathematical or statistical methods”.*

Definition by the International Chemometrics Society (ICS)

Application and development of mathematical and statistical methods to extract information from chemical or process data



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STATISTICAL METHOD USED

- **Multivariate statistical analysis:**
is that branch of statistical analysis which is concerned with the simultaneous investigation of two or more variable characteristics which are measured over a set of objects.



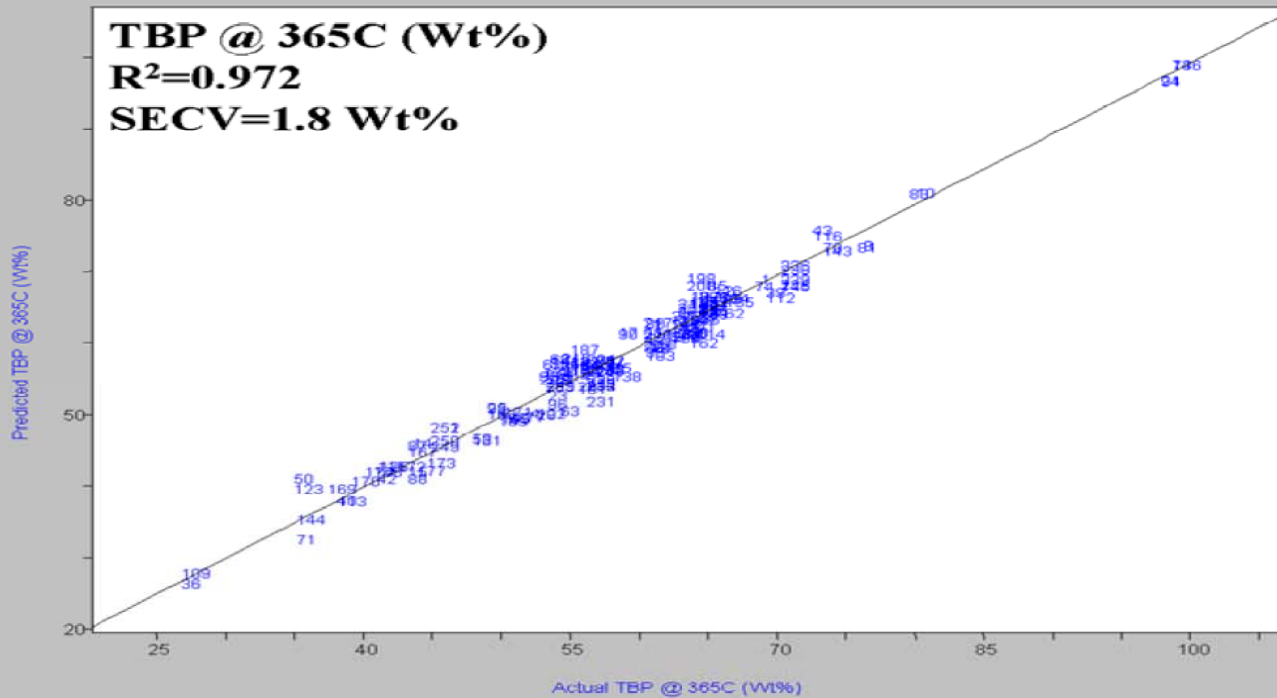
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TBP of Crude predictions





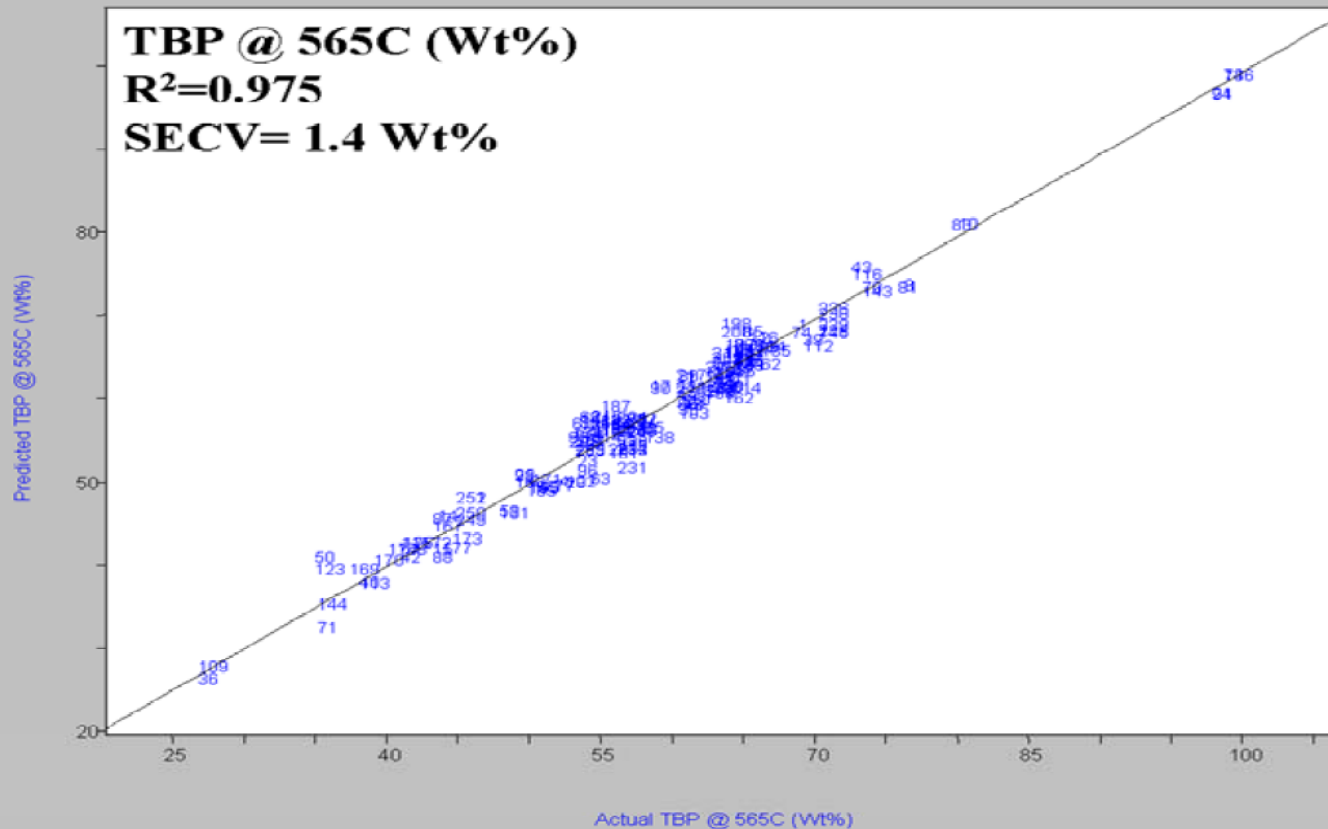
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TBP of Crude predictions





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NMR Models

The models developed for laboratory application are transferable to process application, because both NMR systems are perfectly identical.

MODELS

Accuracy

SECV

C1-C2	0,02
C3-C4	0,66
C5-C65	0,585
65 - 100	0,529
100 - 150	0,671
150 - 200	0,669
200 - 250	0,851
250 - 300	0,66
300 - 350	0,538
350 - 371	0,289
> 371	2,668
371 - 475	1,868
475 - 525	0,629
525 - 560	0,697
> 560	2,235
API	0,55
Sulphur	0,284

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NMR PREDICTION NORMALIZED, API -density, SULPHUR AND TBP CURVE

(*) SECV = Standard Error Cross Validation

MODELS		SECV (*)	PREDICTION	PREDICTIONS NORMALIZED (with SECV and LOSS among all fractions)	COMULATIVE CUT PERCENT FRACTIONS m/m	FRACTIONS	CUT POINT °C	COMULATIVE FOR EACH CUT P POINT PERCENT m/m
API	0,55	35,73	35,73		API			
S % m/m	0,284	0,88	0,88		S % m/m			
C1-C2	0,02	0,04	0,04	0,04	C1-C2			
C3-C4	0,66	2,72	2,57	2,60	C3-C4			
C5-65°C	0,585	4,35	4,22	6,82	C5-65°C	65,0	6,8	
65-100	0,529	5,55	5,43	12,25	65-100	150,0	21,8	
100-150	0,671	9,74	9,59	21,83	100-150	250,0	40,7	
150-200	0,669	9,07	8,92	30,75	150-200	350,0	57,7	
200-250	0,851	10,15	9,95	40,70	200-250	371,0	61,5	
250-300	0,66	9,14	9,0	49,7	250-300	475,0	74,7	
300-350	0,538	8,17	8,0	57,7	300-350	525,0	80,9	
350-371	0,289	3,82	3,8	61,5	350-371	560,0	84,8	
OVER 371	2,668	39,12	38,5	100,0	OVER 371			
371-475	1,868	13,35	13,2	74,7	371-475			
475-525	0,629	6,27	6,2	80,9	475-525			
525-560	0,697	3,97	3,9	84,8	525-560			
OVER 560	2,235	15,33	15,2	100,0	OVER 560			



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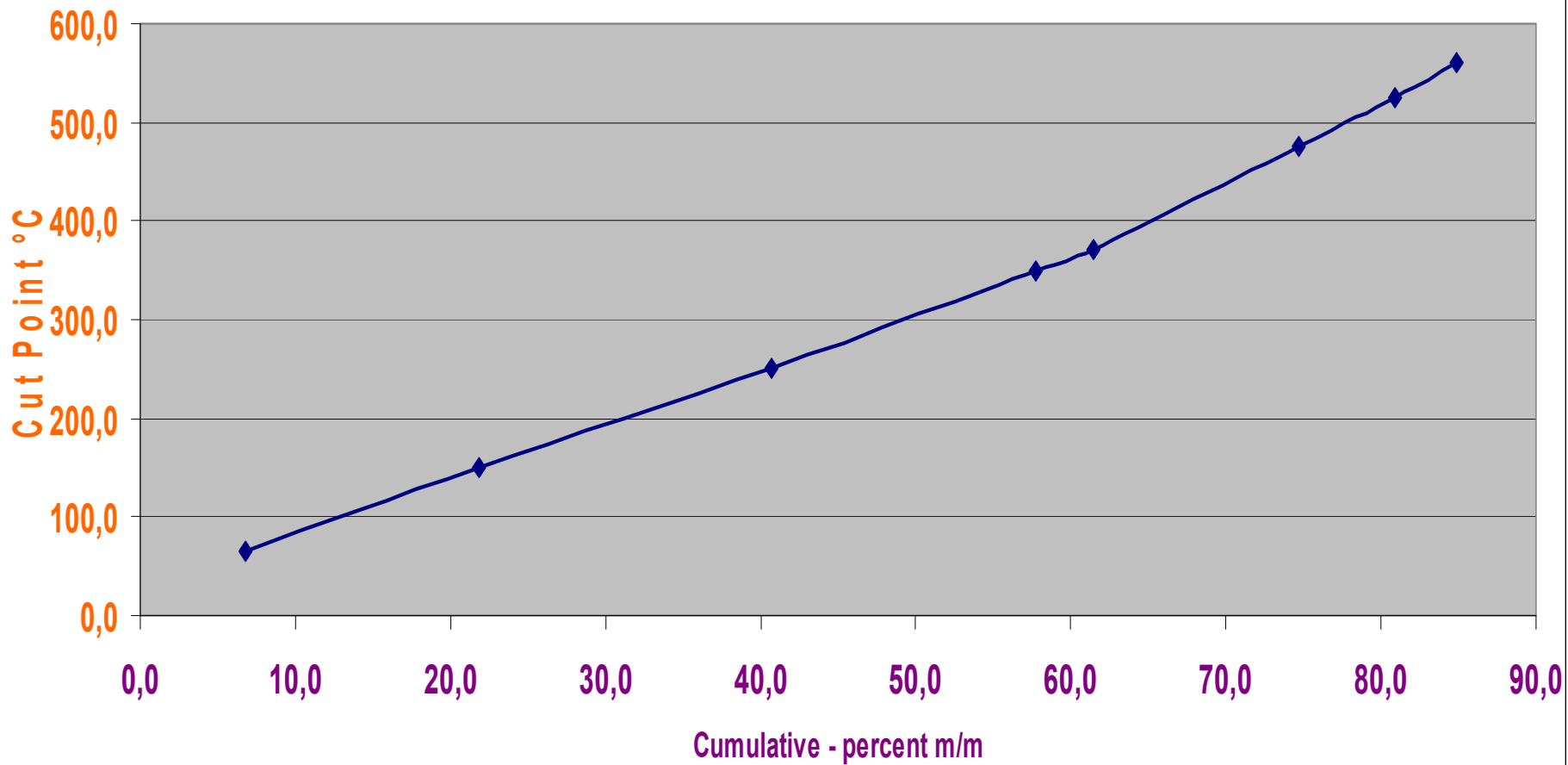
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TBP Curve





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Probationary Validation

Analyzers which employ multivariate models

- 1. Analyzer System Initial Validation**
- 2. Periodic Validation by Plotting Control charts of the Differences Between Methods**

Analyzer System Initial Validation..... (1)

1. Calculate the slope of regression:

$$m = \frac{\sum (PPTM - PPTM_{av}) (PTM - PTM_{av})}{\sum (PPTM - PPTM_{av})^2}$$

between PTM (Primary Test method) and PPTM (Predicted PTM) for 20 validation samples

(properties which are interpolations within the range for which the calibration was developed and validated- cross validation. Further, sd of PPTM should be at least 72% of the Reproducibility of the primary method);

2. Calculate the standard error of the regression coefficient (Sm);

$$S_m = \sqrt{\frac{\sum (PTM - PTM_{av})^2 - m^2 \sum (PPTM - PPTM_{av})^2}{(n-2) \sum (PPTM - PPTM_{av})^2}};$$

3. Compare m/Sm to the 95° percentile of Student's distribution with n-2 degrees of freedom (n=20);

4. Compute the differences between the PPTM and PTM for n initial validation samples (20)

$$d_i = (PPTM - PTM)_i;$$

5. Detect outliers using the ESD (Generalized Extreme Standardized Deviation) method:

$$ESD_i = |d_i| / s; \text{ where } s \text{ is the standard deviation in the } d_i;$$

6. Construct the probability Plot (the plot should be approximately linear) after outliers are eliminated;

.....**Analyzer System Initial Validation (2)**

- 6. Compute the bias for the probationary validation (as the average difference between PTM and PPTMR: d_{av});**
- 7. Compute the variance for the probationary validation (S^2_d) and Compute t ($|d_{av}| * \sqrt{n} / \sqrt{S^2_d}$);**
- 8. Compare the computed t value with the critical t values for $(n-1)$ degrees of freedom;**
- 9. Calculate the mean square error for PPTM ($SE^2_a = \sum(PPTM - PTM)_i^2 / n$);**
- 10. Compare the SE^2_a to $SECV^2$ using F- distribution test;**
- 11. Calculate the F value as follows: $F = SE^2_a / SECV^2$ for $SE^2_a > SECV^2$ and $F = SECV^2 / SE^2_a$ for $SE^2_a < SECV^2$;**
- 12. Compare the value of F with the limiting F value, the number of degrees of freedom for numerator and denominator are $n-1$ and $m-1$ (where m is the number of model validation samples 30 for NMR models).**

Periodic Validation by Plotting Control charts of the Differences Between Methods

1. Check the stability of the differences between PTM and PPTM using the control

three types of control charts;

2. Establish the initial control limits for these charts by:

2.1 Compute the differences, d_i , for the initial validation samples: $n=20$

2.2 Compute the mean difference \bar{d} and moving range MR_{av} (MR-bar):

$$\bar{d}_{av} = \sum d_i / n \quad ; \quad MR_{av} = \sum |d_{i+1} - d_i| / n - 1$$

2.3 Construct the Individual values control chart for differences with the following control limits:

$$UCL_d = \bar{d}_{av} + 1,77 MR_{av} \quad \text{and} \quad LCL_d = \bar{d}_{av} - 1,77 MR_{av} \quad ; \quad (1,77 = 2 \sigma = 95,4 \% p)$$

2.4 Construct Exponentially weighted Moving average Control charts for the differences using

λ (weight) = 0.2 to 0.4, corresponding 1.0 to 1.5 σ , overlay the individual values chart, with the

following control limits: $UCL_\lambda = \bar{d}_{av} + 1,77 MR_{av} \sqrt{\lambda / 2 - \lambda}$; $LCL_\lambda = \bar{d}_{av} - 1,77 MR_{av} \sqrt{\lambda / 2 - \lambda}$.

Calculate sequence values, w_i , and plot them : $w_i = (1-\lambda) w_{i-1} + \lambda d_i$; where $d_i = (PPMT - PMT)_r$

2.5 Construct a separate MovinRange of Control Chart. The control limits are given as :

$UCL_{MRav} = 3.27 MR_{av}$; $LCL_{MRav} = 0$. Plot the values given as: $MR_i = |d_i - d_{i-1}|$, connect each point.



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Open the file:

Probationary Validation

Tests for the following properties.

Density API,

Sulphur,

TBP Fractions:

C5 – 65°C

100-150 °C

200-250 °C

300-350 °C

Over 371 °C

475-525 °C

Over 560 °C



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C₅-65 °C

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Sample	Ya	Yr	Bias
R6	4,50	3,80	0,70
R14	4,60	3,80	0,80
R24	3,80	3,40	0,40
R25	3,60	4,20	-0,60
R34	3,30	2,50	0,80
R35	4,40	4,50	-0,10
R36	3,80	3,70	0,10
R39	3,70	4,10	-0,40
R42	3,70	2,90	0,80
R44	4,00	4,50	-0,50
R46	2,70	1,90	0,80
R65	6,00	4,70	1,30
R70	3,70	5,00	-1,30
R68	2,30	1,60	0,70
R69	2,10	2,20	-0,10
R72	4,70	5,20	-0,50
R73	4,10	3,20	0,90
R74	3,10	3,10	0,00
R75	3,90	4,20	-0,30
R76	4,20	3,90	0,30



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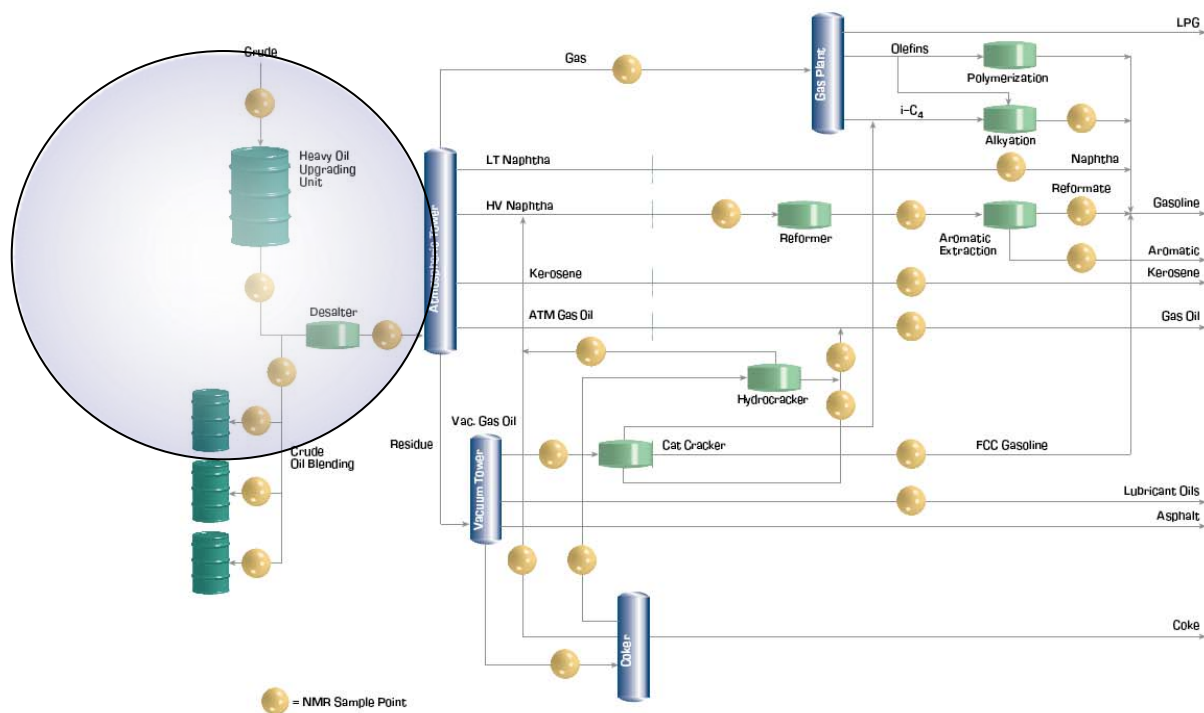


475-525 °C

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Sample	Ya	Yr	Bias
R1	6,30	7,60	-1,30
R2	6,00	6,00	0,00
R4	5,60	5,50	0,10
R6	6,70	7,70	-1,00
R14	6,60	8,10	-1,50
R24	7,10	8,80	-1,70
R34	6,20	6,00	0,20
R35	6,90	8,10	-1,20
R36	5,10	4,40	0,70
R39	7,60	8,70	-1,10
R42	5,40	5,30	0,10
R44	7,10	6,70	0,40
R46	5,40	5,90	-0,50
R65	7,10	7,30	-0,20
R70	4,40	5,40	-1,00
R68	7,00	5,80	1,20
R69	8,20	7,70	0,50
R72	8,10	7,30	0,80
R73	5,90	5,10	0,80
R76	6,90	7,50	-0,60

Key application: Crude feed & distillation





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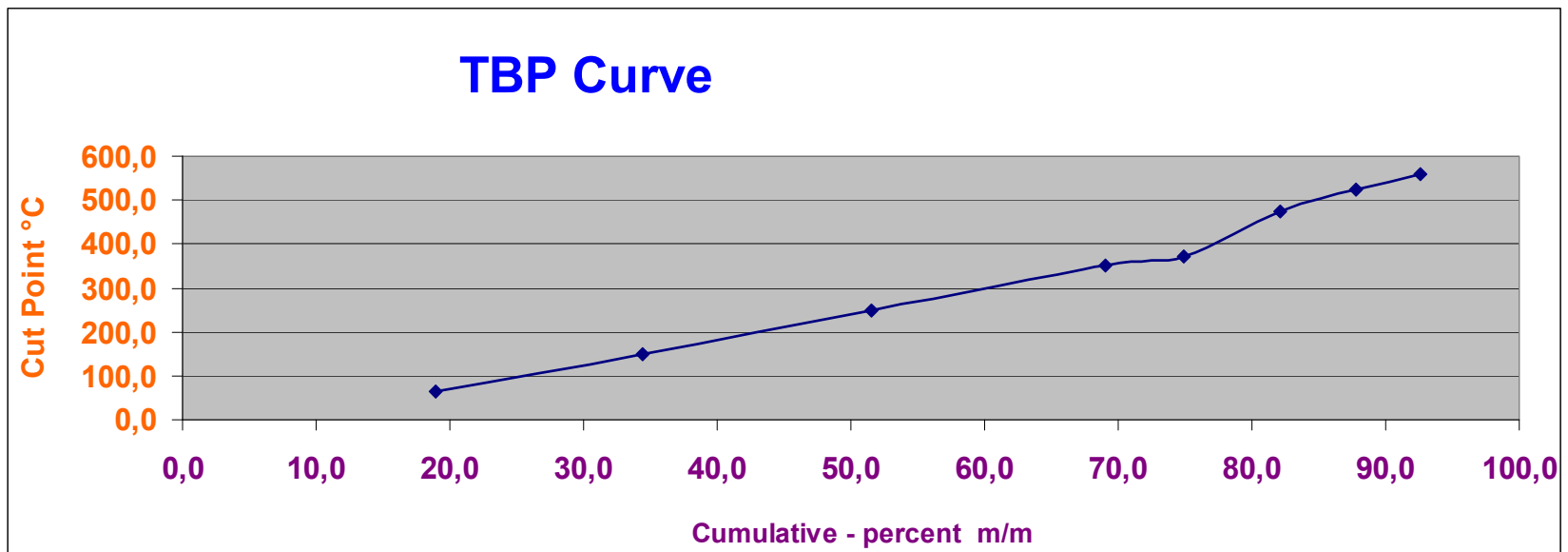


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Open the File:

NMR Fractions Normalized

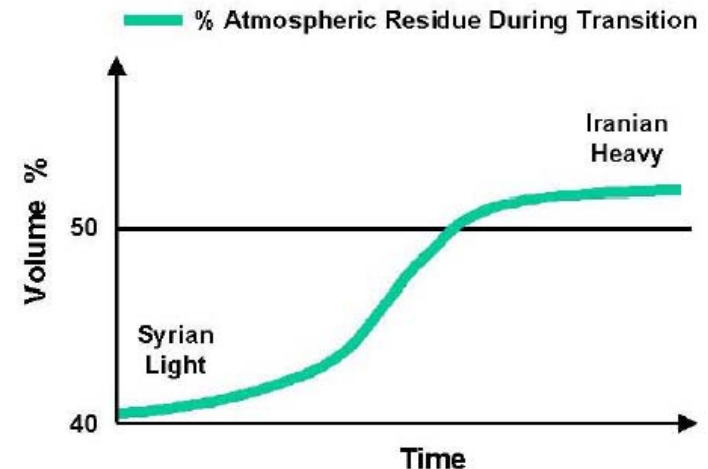
Connection to the PI system (Plant Information) so that we have the variations TBP curve of the Topping feedstock in real Time



Effect of crude quality variation on CDU

- Cut point optimisation affected
- Product quality control risks
- Feed rate is not maximised
- Energy consumption not optimal
- Risk of violating the process equipments constraints

- Unit operating conditions are upset by changing feed composition
- Product slate is not maintained at optimum
- User incurs significant financial penalties





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Thanks for Your attention !!!