



## Gamma Scan Data Analysis using Segmented FFT Method to Verify Liquid Maldistribution in Distillation Column of VDU

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*Received 27 December 2021; accepted 14 January 2022*

Gamma scanning of the VDU was performed, to verify proper liquid distribution in the column section near Bed number 3. Gamma scanning was carried out in four chords and across two diameters 90 degrees apart. The recorded detector response (count-rate) data of each scan had analyzed using graphs, by co-relating it with column internals and also by comparing with each other. It was concluded that due to a faulty liquid distributor, the liquid is distributed unevenly in Bed number 3 of the column. This work has been published in 2016. From the graphs, it was not easy to derive the conclusions quickly. Also, the analysis done using graphs is qualitative in nature. The paper describes the study carried out to analyze the same data using the new segmented FFT method, without using graphs. In the study, the data was transformed into the frequency domain and then analyzed to interpret liquid maldistribution in the column. The results of the proposed segmented FFT analysis method are encouraging. It is concluded that the segmented FFT method of data analysis is better than the conventional chart-based method. Also, it is simple, fast, and quantitative.

**Keywords:** segmented FFT, Gamma scanning, discrete Fourier transform

### 1 Introduction

Gamma scanning of columns is very popular in the petrochemical industry, to identify various operational troubles without disturbing column operation<sup>1</sup>. The technique is in use for more than four decades in the industry and was initially applied for tray-type distillation columns to identify structural damages. However, over the years it has improvised its performance. Today, gamma scanning is used on all types of columns to identify the internal and operational troubles and to optimize the column for improved performance, efficiency, and quality of the final product. For the packed bed column, the grid scanning technique is used. In this technique, a column under observation is scanned in four chords<sup>1</sup>. Scanning is generally performed externally by placing a gamma radiation source and detector, along the chord. The response of the detector to transmitted gamma-ray through the column internals is recorded, at regular intervals of elevation. The detector's response plotted against the elevation is called the gamma profile of the column. These profiles are analyzed to identify various column troubles. For packed bed columns, the detector response graphs (gamma profiles) are analyzed by correlating with

column internals and comparing them with each other to identify liquid mal-distribution. But this analysis is not simple, because one cannot control many dynamic conditions of the scanning. Also, only an expert interpreter can read useful information from the gamma profiles. The success of gamma scanning is largely dependent on the knowledge and experience of an expert interpreter.

The liquid maldistribution was reported in the specific portion of the column having Packed-Bed#3 of Vacuumed Distillation Unit (VDU). The section of the column had investigated using gamma scan, to verify the improper distribution of the liquid and to identify the exact cause of the problem<sup>2</sup>. The column had been scanned six times, four scans were performed placing gamma source and detector in four chords, and the remaining two scans were performed across the diameter, 90 degrees apart as shown in Fig. 1.

The detector response (count-rate data) graph of each scan was plotted for analysis. From graphs, it was concluded that the liquid is distributed unevenly, inside the column, due to a faulty liquid distributor<sup>2</sup>. This work is published in 2016. The analysis done using charts is qualitative in nature. The interpretation was derived after careful analysis of each chart. Also, each chart was compared with the column details and other charts to reach some conclusion, which was

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time-consuming and tedious due to unequal detector responses.

These drawbacks of the graph-based analysis method motivate one to look for another method of data analysis. One of the ways is to convert the data to some other domain for analysis, rather than its own domain. The paper describes a new segmented FFT analysis method to analyze the data in the frequency domain. The aim of the study is to simplify the method of analysis so that it gives analysis results faster and reduces the complexity of analysis. Also, the new method should be better than the conventional ones on the basis of merits and demerits.

**2 Methodology**

The original data of the gamma scan had been collected at every 30mm distance (total ~192 data points, 5760mm) over a span of the column under investigation as shown in Fig. 1. Out of six scans, data of only the four scans L1, L2, L4, and L6 used in the study, as together it covers ~60% portion of the whole cross-section of the column. The L1 scan line covers the southwest direction, L2 the Northwest direction, L6 covers the southeast, and L4 covers the northeast direction of the column. So together L1 & L2 covers

the west half and L4 & L6 covers the eastern half of the column. Similarly, L2&L4 together covers the north half, and L1&L6 together covers the south half of the column.

**2.1 Data treatment**

The real data of the gamma scan has discrete values of radiation counts. It is known that when a signal is sampled in space or time and amplitude is discrete, the discrete Fourier transform (DFT) is used to transform it to the frequency domain<sup>3</sup>. In gamma scanning, the radiation level recorded over a period of time is discrete data of the column internals sampled over its height. It is a discrete data signal that represents variation in the column's internal average density with respect to the elevation. This data is in space/time-domain and can be represented mathematically as  $R_n = [R_0, R_1, R_2, \dots, R_{N-1}]^D$  where N is the total number of readings (samples) recorded over an elevation D (time period T). The DFT of this column signal is given by

$$C[m] = \sum_{n=0}^{N-1} R[n]e^{-j2\pi mn/N} \quad m = 1,2,3, \dots, N \quad \dots (1)$$

Where  $C_m$  are complex coefficients of the series with real and imaginary parts. DFT transforms the time-domain data into frequency-domain data. This transformed data is a Fourier series ( $C_m$ ) and its first coefficient is a real number without any imaginary component. This first FFT coefficient ( $C_1$ ) has been taken for quantitative analysis of the data.

The original data of each gamma scan is divided in such a way so that the first data segment (ID1) shall cover the cross-section of the liquid distributor (spray header), the second segment (ID2) shall completely cover the top portion of bed#3, third segment (ID3) shall cover the bottom portion of bed#3 and so on. The data of each segment of each scan line was transformed into the frequency domain using the FFT algorithm and normalized for unequal data points. From the normalized data series, only the  $C_1$  value was recorded, as shown in Table 1.

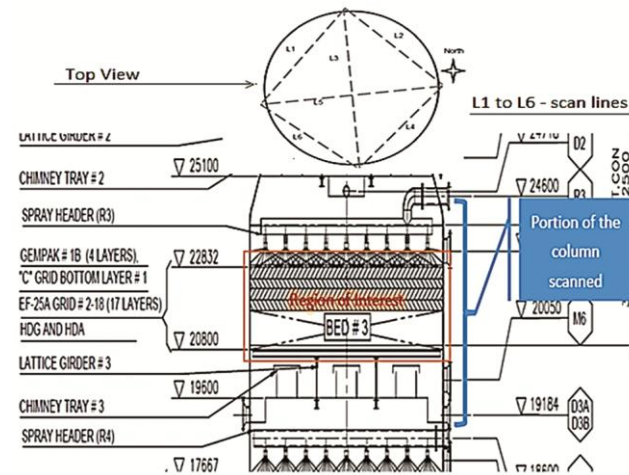


Fig. 1 — Portion of the VDU column scanned and number of scan lines

Table 1 — Segment wise values of First FFT coefficient ( $C_1$ ) of scanline L1, L2, L4 and L6

Component of the VDU column	Elevation (mm)	Segment ID (data points)	$C_1$ -L1-SW	$C_1$ -L2-NW	$C_1$ -L6-SE	$C_1$ -L4-NE
Spray Header (3)	5760-4860	1 (30)	107	93	129	304
Top Portion of Bed#3	4860-3600	2 (42)	36	80	31	78
Bottom Portion of Bed#3	3600-2670	3 (31)	23	19	18	19
Lattice Girder #3	2670-1770	4 (30)	27	35	22	41
Chimney Tray#3 bottom	1770-1020	5 (25)	19	23	12	22
Spray Header (4)	1020-0000	6 (34)	72	26	60	116

Table 2 — Prediction of liquid mal-distribution from  $C_I$  value of four scan lines of gamma scan

Segment ID	$C_I$ -L1	$C_I$ -L2	$C_I$ -L4	$C_I$ -L6	reference (R)	Prediction
1	107	93	304	129	158±47	Very Less liquid in L4 (northeast side) and very little more liquid in L1&L2 (west side)
2	36	80	78	31	56±17	Less liquid in L4 and L2 (north side)
3	23	19	19	18	20±6	equal or even liquid distribution
4	27	35	41	22	31±9	little Less liquid in L4 (northeast side)

Table 3 — Prediction of liquid mal-distribution based on ratio-based comparison of  $C_I$  values

Segment ID	L2/L1	L4/L6	L2/L4	L1/L6	Prediction
1	0.87	2.35	0.3	0.35	Less liquid in northeast side, more liquid in west side
2	2.22	2.5	1.02	1.16	Less liquid in north side
3	0.82	1.05	1.00	1.28	Even liquid distribution
4	1.29	1.86	0.85	1.22	Less liquid in northeast side

## 2.2 Analysis

The purpose of the analysis of gamma scan data is to verify the liquid maldistribution in the column around bed#3. So, for analysis, only the first four segments were considered. The First FFT coefficient ( $C_I$ ) of the scan line segment represents the average change in the density of the medium seen by that scan line. This change is mainly due to the presence of liquid in the column in the respective portion of the column plane as the remaining components of the column internal are static. The  $C_I$  values of the segmented data obtained after Fourier transform are recorded. To analyze liquid maldistribution, two comparison techniques have been used to validate the results.

In the first method, calculated the average value of  $C_I$  of each segment and identified it as a reference value (R) of comparison for that segment, as shown in table 2. The range of reference, for comparison, is set  $\pm 30\%$  of the reference value. This is mainly the measurement error of input data (detector's response to gamma radiation). If the  $C_I > R_{max}$  it indicates less liquid in that section and if  $C_I < R_{min}$  then predicted as more liquid than the normal. Whereas, when the  $C_I$  value is within the limit  $R_{max} > C_I > R_{min}$ , it is predicted as an even liquid distribution. Applying this criterion, the interpretation of each segment has been carried out and the predictions are listed in Table 2.

In the second method, a ratio-based comparison was carried out for prediction. The ratio of the  $C_I$  values of each segment of the scan lines L1, L2, L4, and L6 is taken as shown in Table 3. As the scan lines, L2 and L4 are on the north side, the ratios L2/L1 and L4/L6 are comparing the north half with the remaining half of the column. Similarly, the ratios L1/L6 and L2/L4 compare the west half with the east half of the column. In the ideal conditions, the ratio

value one indicates the liquid is equal in both parts. Thus, it may be predicted that the liquid quantity has equally distributed in both the scan line portion of the column. When the ratio is greater than or less than one, it indicates unequal liquid distribution. Considering measurement error of  $\pm 30\%$ , it was decided that the ratio value above 1.3 shall indicate the less liquid quantity, and the ratio value below 0.7 shall indicate more liquid quantity. Applying this criterion, the interpretation of each segment has been carried out and the results are listed in table 3.

## 3 Results and Discussion

From Table 2, it is observed that for segment ID3 (the lower portion of bed#3) the  $C_I$  value of all the four scan lines (L1, L2, L4, and L6) is within the range of reference value. This shows an equal amount of liquid present in all four sides of the column. Further, in segments ID1, 2, and 4 the  $C_I$  value of the scan line L4 satisfies the criteria  $C_I > R_{max}$ . Thus, less liquid is predicted on the northeast side of the column. This clearly verifies maldistribution in the column.

Further, in segment ID1 it is observed that the value of  $C_I$  of L1 & L2 is smaller than the  $R_{min}$  value. This suggests that the quantity of liquid in the Northeast direction of the column is very less than in the southwest and northwest. This also means the quantity of liquid is less in the east direction of the column than in the west. Further, the  $C_I$  value of L4 is much higher than the  $C_I$  value of L6. This suggests that the liquid is very less on the northeastern side than on the southeastern side in this segment. In segment ID2, the  $C_I$  values of L2 and L4 are higher than the reference, which indicates less liquid is present in the Northeast and Northwest directions. Both the  $C_I$  values of L2 and L4 are almost equal which shows liquid is less in the North than the

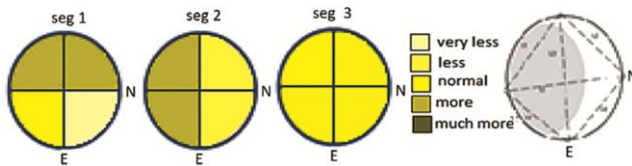


Fig. 2 — Conceptual picture of segments of the column based on  $C_I$  and old result.

Southside in the top portion of bed#3 of the column. In segment ID3, which is the bottom portion of bed#3, all the  $C_I$  values are within the reference range. This suggests uniform liquid distribution in this segment. In segment ID4, again, less liquid is indicated, by the  $C_I$  values of the L2 & L4, in the northeast and northwest direction. This means less liquid is on the north side than the south side of the column.

The result listed in Table 3 shows that, for segment ID1, the value of L4/L6 is nearly double than reference range ( $1 \pm 0.3$ ). It indicates that a very less quantity of liquid is falling on the northeast side of the column in the spray header section. Also, the values L1/L6 and L2/L4 show that liquid is less on the east side than on the west side. For segment ID2, the L2/L1 and L4/L6 values are higher than the reference hence indicating less liquid on the north side of the top portion of bed#3. All the values in segment ID3 are within the range ( $1 \pm 0.3$ ) which indicates equal liquid distribution in the lower half of bed#3. In segment ID4, again the value L4/L6 suggests less liquid on the northeast side of the column. From this, it is understood that the maximum problem is in segment ID1 where the spray header is located. From these results, it is concluded that less liquid is received in the upper half portion of bed#3 on the north side, as very little liquid may be falling from the spray nozzles, on the north side of the column.

From these interpretations, a conceptual picture of the liquid distribution in the first 3 segments of the data is developed as shown in Fig. 2. It also shows the conceptualized picture of the liquid distribution in the upper portion of bed#3, drawn using conventional analysis<sup>2</sup>. It is observed that the conceptual picture of segment ID2 (top portion of bed#3) matches it. This shows that the results obtained applying the new segmented FFT analysis method on the practical data of VDU gamma scan are in agreement with the earlier results, obtained using the conventional method of analysis.

It again confirms that both methods of analysis give the same results. Hence, it is concluded that the time domain data can be analyzed in the other domain too. The earlier results were derived by comparing charts of L1 with L2 and L4 with L6. The ratios L2/L1 and L4/L6 (Table 3) of  $C_I$  values do the same work. However, when the proposed segmented FFT analysis method is used it becomes very easy to interpret the liquid quantity from the ratio values and the set criteria of analysis. Seeing the numerical values, one can very easily predict that at segment ID1, 2, and 4, liquid in scan line L4 is less than scan line L6. Additionally, the L2/L4 and L1/L6 ratios clearly indicate unequal liquid distribution in segment ID1 but, not in segments ID2, 3, and 4. From this, it is concluded that the proposed segmented FFT analysis method is simple and faster. Also, it is better than the conventional method.

#### 4 Conclusion

The first coefficient of the transformed Fourier series (FFT) contains adequate information of the gamma scan which may be used to examine and analyze the data. It is useful for quantitative analysis. The data analysis carried out using the segmented FFT method reduces the complexity and simplifies data analysis. The method shows superiority to conventional chart-based analysis, being simple, fast, and quantitative. This method is very useful in the case of grid scans or when there are multiple scans. The success of the proposed method largely depends on proper segmentation of data and identification of the correct reference value. These features limit its application on a single gamma scan data in some cases.

#### Acknowledgement

The authors are thankful to the staff of the Isotope Applications section of BRIT for help and support provided during the study. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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