C. 산업현장에서의 실시간 최적화

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산업현장에서의 실시간 최적화

(실시간 물성 데이터를 이용하는 상압증류공정 최적화를 중심으로)

1. Introduction

Near-Infrared (NIR) Spectroscopy is a newly emerging and very powerful vibrational analytical technique. While the conventional analyzers in refinery require the analysis time of 20 to 180 minutes, NIR can provide highly accurate real-time analytical data in less than one minute. In addition, NIR is cost effective because multiple properties can be simultaneously measured using a single spectrum and it is also safe because the measurement instrument can be located away from hazardous environments using optical fibers. These advantages of NIR Spectroscopy make itself an efficient tool when combined with recent advanced process control or real-time optimization techniques. Since the first application of NIR to gasoline blending in 1993, SK corporation (formerly Yukong) has made an outstanding technology development for the application of NIR spectroscopy into various refinery and petrochemical processes such as Gasoline Blending, Diesel Blending, Crude Distillation, p-Xylene, Naphtha Cracking, Lube Base Oil, Solvent, etc.

In this lecture, basic introduction to NIR Spectroscopy will be briefly given first and then the actual use of real-time NIR data for the improvement of APC and optimization will be discussed. In the discussion, new concepts of APC and On-line optimization using real-time NIR property data are introduced with the actual examples in SK's plant sites. Even though more emphasis will be put on the application to Crude Distillation Units, application results to other processes such as gasoline blending will also be introduced to give audience a general idea of utilizing real-time NIR data to improve operation in the refinery and petrochemical processes.

2. NIR Spectroscopy

2.1 General Introduction to NIR Spectroscopy

Near-Infrared (NIR) spectroscopy is a vibrational analytical technique. The NIR frequency is located in a region between the visible mid-infrared (Mid-IR) and 780 to 2500 nm of electromagnetic spectrum. Absorption bands in the NIR region are related to the overtone and combination bands of fundamental vibrations of CH, NH, and OH groups in the mid-infrared. Highly overlapping absorption peaks make spectra too complex to interpret qualitatively and the dramatic loss of sensitivity (low absorptivity) limits the qualitative analysis. NIR intensities are much weaker than Mid-IR intensities by a factor of 10 to 1000.

However, with advances in chemometrics NIR spectroscopy is emerging as a valuable analytical tool. At first, NIR spectroscopy was applied to the analysis of agricultural products. And its application has been expanded to the measurements in clinical chemistry and in the petrochemical, pharmaceutical and beverage industries. The most important advantage of NIR is that it provides highly precise real-time analytical data in less than one minute while the conventional analyzers in refinery requires 20 to 180 minutes of analysis time depending on the properties to be analyzed. This highly precise and fast NIR measurement can be efficiently combined with advanced process control and real-time optimization which is practically impossible with conventional analyzers. In addition, NIR is more practical for remote sensing and on-line measurement because NIR can be easily combined with fiber optic technology for the transmission of NIR radiation. Using optical fibers, the measurement instrumentation can be located away from hazardous, radioactive or explosive environments. Additionally multiple properties can be simultaneously measured by using only one spectrum. As a result, not only the efficiency of analysis is improved but also the investment cost for analyzer is greatly decreased. For a graphical example of NIR spectroscopy, please refer to Fig.1.

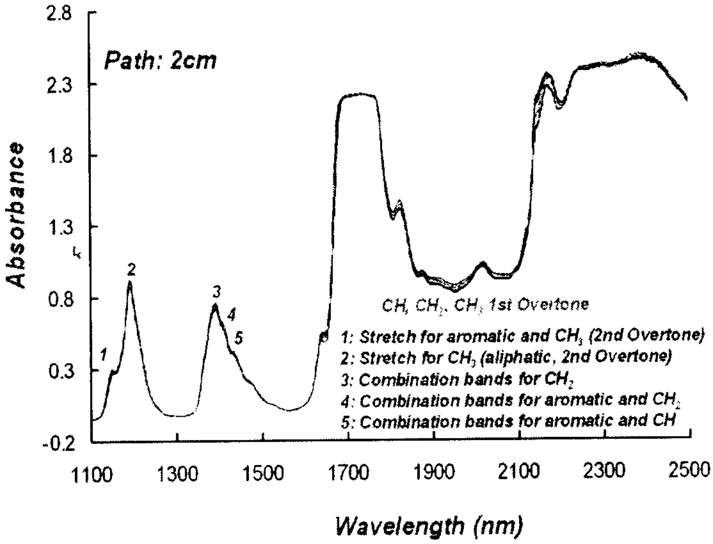

Fig.1. NIR Spectra of Gasoline

2.2 NIR Spectroscopy in Crude Distillation Unit

The on-line property measurement of feed and product streams in Crude Distillation Unit (CDU) using NIR spectroscopy is much more difficult than any other clean and pure streams such as in petrochemical processes. Because the light transmittability of crude oil is very low due to its dark color, it is very difficult to obtain a clear NIR spectrum from a crude oil. And because there are too many sources of crude oils available around the world, the development of one robust method of NIR analysis is also very difficult. Besides the crude oils, the on-line analysis of product streams out of CDU has also many complications. During the crude distillation process water or chemicals should be inevitably added, and those added components work as impurities from the viewpoint of NIR spectroscopy. Those impurities make the NIR spectrum very poor and the correct property measurement becomes almost impossible.

After several years of efforts, SK has developed its own method to apply the NIR technology in real-time to CDU. Two most important factors for the success of the method are the performance of sample conditioning system and the precision of calibration model. These two factors cannot be satisfactory if not based on the deep process knowledge and the close communication between model developer and lab technician. Fortunately, SK could make a task force team whose members are composed of process engineers, control engineers, lab technicians, chemists. The models could also be tested in the real process inside SK Corporation. These are how we could make NIR technology work on-line in CDU. Typical process streams in CDU and the available on-line NIR data are shown in Fig.2. And some typical performances of the NIR analysis are given in Fig.3.

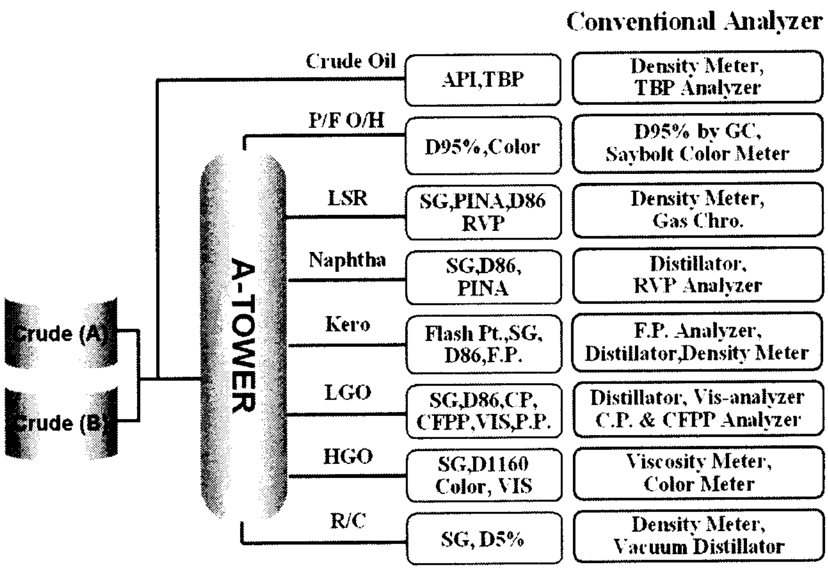

Fig.2. Required analysis for crude unit operation

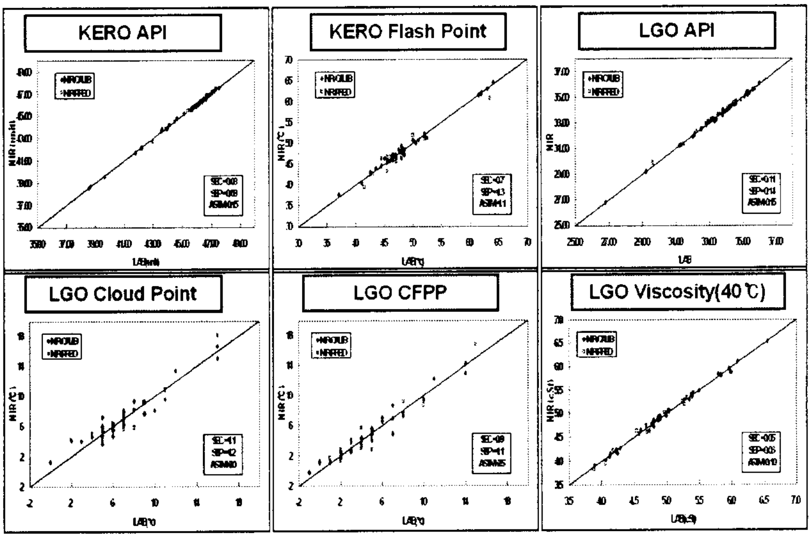

Fig.3. API, Flash point, Viscosity, Cold property Kero/LGO

3. On-line Application of NIR to Crude Distillation Unit

3.1 Conventional CDU Operation

Even with the recent advances in the area of process control and optimization, the true optimal operation of CDU has never been perfect in the real world due to the unmeasured feed property change or the incorrect product property estimations. Typical scheme of the conventional CDU operation is in Fig.4.

A typical examples of higher value product loss or unstable CDU operation due to the unknown feed property change are in Fig.5. In a refinery, an operation guide for a new crude charge is usually generated based on a crude assay calculated off line using a software tool. However, the calculated assay may not be accurate due to incomplete mixing, inaccurate blending operation or delayed assay updating. And even though the calculated assay of charging crude was correct at the beginning period of a crude batch, the crude property may also be changed during the operation by settling inside tank. So to keep the CDU stable and optimal, real-time monitoring of crude property change is necessary. However, there has not been any robust method available so far to monitor the crude change in real time.

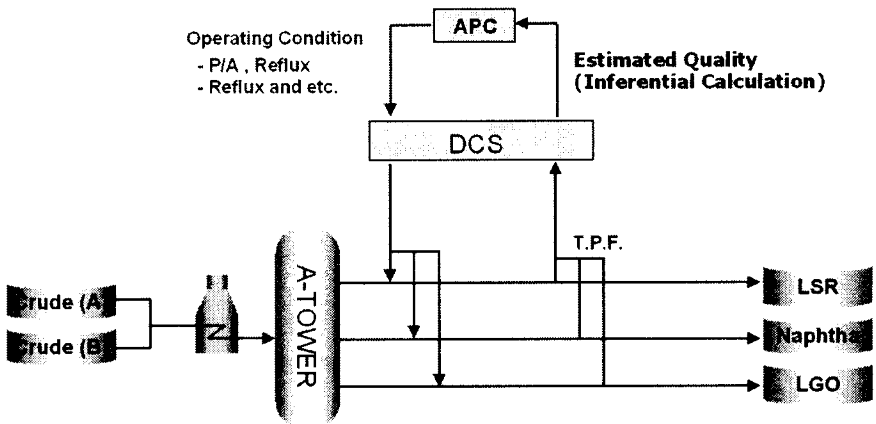

Fig.4. Conventional CDU Operation

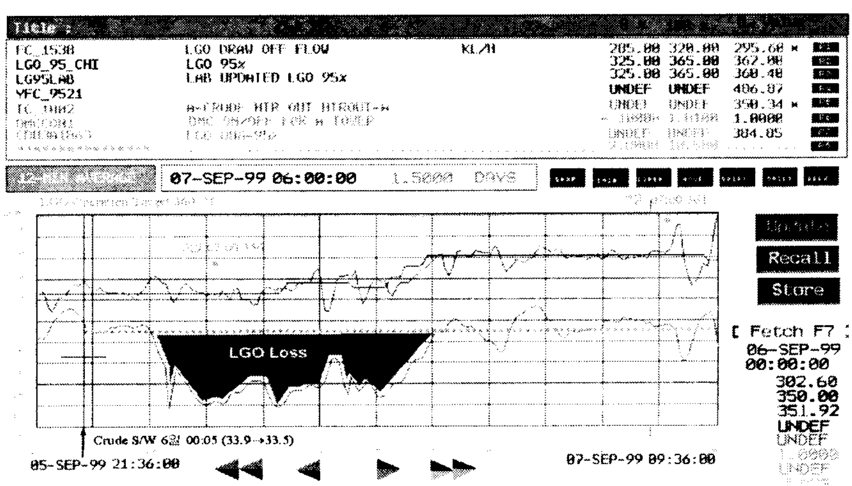

Fig.5. Decrease of LGO production during crude switch

Inaccurate product property estimation also limits the optimal operation of CDU. Even though there has been numerous way of estimating property in real time using inferential model, no perfect method available. Inferential model may be correct in some operating region. However as operating condition changes the inferential model begins to deviate from where it was tuned, and the model should be updated based on a new result of lab analysis which usually takes several hours to as long as a whole day. In other words, the operation should be kept loose not to produce off-spec product until the lab result confirms the inferential model. Usually inferential model is made insensitive compared to lab result to avoid sudden change of process, which also limits the optimal operation of CDU.

Finally, because no real-time property data of charging crude and products are available, optimization based on a rigorous model is limited to a heat and material balance without considering property values. Heat and material balance optimization considers only temperatures, pressures or flow rates, which can be measured on-line without difficulty. It should be noted that the values of products might differ depending on their properties even though the products are within given specifications.

3.2 On-line Optimization of Crude Units

3.2.1 Background for the On-line Optimization of Crude Units.

In the refinery, final goal will be maintaining each step of planning/ scheduling/ operation(control) loop optimal and also maintaining the loop fully automated. As shown in the Fig.4, DCS and APC is used very widely in usual refinerys. However, setpoints are given by experienced operator or by LP model which is in the APC package. So, if the property data mentioned above is available, next step for the automation of chemical processes will be on-line optimization. The importance of on-line optimization of a refinery is based on the fact that there is so many disturbances which may cause change of operation conditions to maximize its profit. Some people think that off-line optimization (optimize once after crude mixture is changed and keep the setpoint until next crude change) is good enough to recover most of potential profit from a refinery because crude change is biggest disturbance. However, even after crude tank is changed, the composition of charged crude may vary as tank level goes down as shown in Fig.6. This is one of many disturbances which justify on-line optimization for the refinery or petrochemical processes.

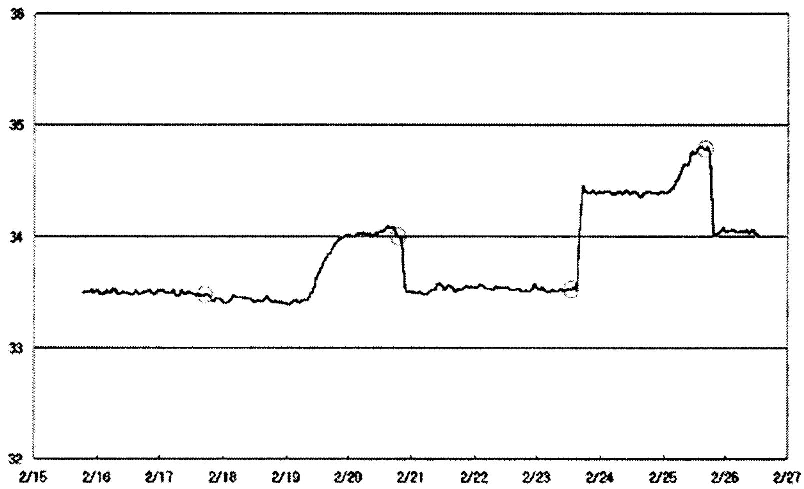

Fig.6. API trend of a charged crude mixture

On the other point of view, on-line optimization may be an important pin linking scheduling step and operation step of Planning/ Scheduling/ Operation loop. On-line optimization package is usually composed of two part, process model and on-line executor. On-line executor links process RTDB to model variables and execute the sequence of on-line optimization programed in it by user. Process model should be somewhat different from usual ones using general process simulator because the result is applied to real plant directly skipping review by human. That means it should be more robust and more rigorous and very fast in optimization calculation. Usually, open equation model based simulator is used for this purpose. Fig.7 shows a typical procedure of on-line Optimization.

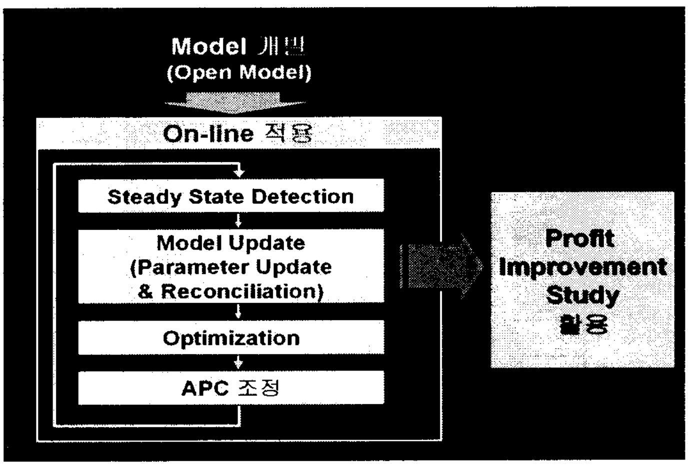

Fig.7. A typical procedure of on-line optimization

In the model update step of Fig.7, model receives all the measured value of the process from RTDB and update parameters like U value of heat exchangers and reconcile measured errors. From the start-up of a process to the shut-down of it, on-line model shows same performance with actual plant by the model update step. So, the quality of measured data is one of the most important element for the on-line application of a model. The result calculated by the optimization step of Fig.7 is given to APC. We need to define DOF(Degrees of Freedom) of the process and choose same numbers of external target for APC.

Temperature, Pressure, Flow rate are what we may have by on-line from current refinery. However, there is many other data like petroproperties which should be met as specifications of products. On-line measurement of petroproperties will let us recover more profit lost by insufficient information. Next section will describe how we can get these properties and apply them to on-line optimization.

3.3 Improvement using Real-Time NIR Data

The improvement of CDU operation by using real-time NIR data can be explained straightforwardly if the limitations of conventional CDU operation are understood. Conceptual diagram of CDU operation with NIR is given in Fig.8.

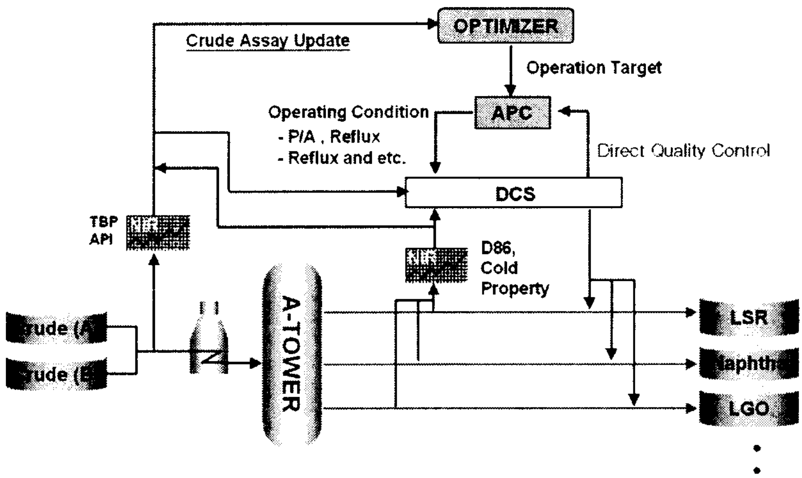

Fig.8. CDU operation with NIR

First, if we can know in priori the optimal yields of each product to be produced corresponding to current crude being charged, neither too much product nor too small product would be drawn off, so that we can avoid the yield loss or the process instability during crude switching period. Graphical example of benefit during crude switch is given in Fig.9. And as can be easily seen without detailed explanation, very tight quality control of products also becomes possible by knowing the accurate property data of products in real time. These advantages of real-time NIR can be easily combined with existing APC by defining the crude NIR data as feed-forward variable and replacing the existing inferential model with the product NIR data even though a little tricky operation of raw NIR data is required before the actual use.

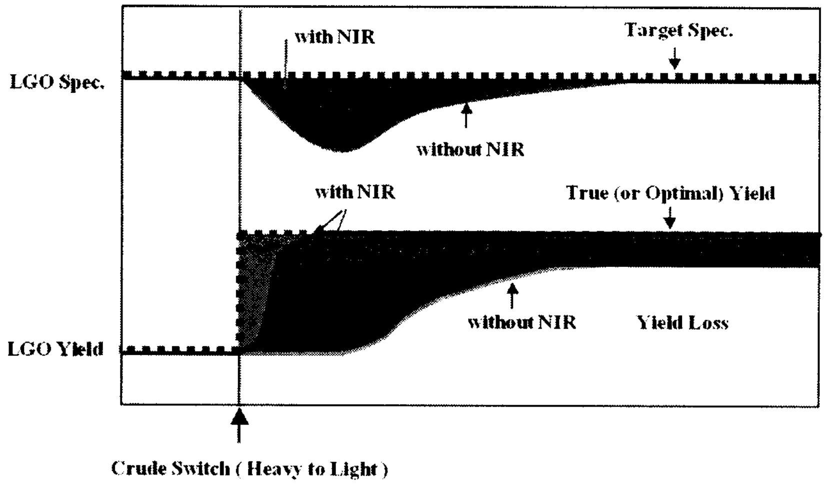

Fig.9. Benefits of APC & OPT with NIR during crude switch

Second, quality of optimization is improved drastically by using the property data of feed and products in real time. As explained already, the current heat and material balance based optimization is upgraded to a quality (or property) based optimization. An example is a naphtha stream optimization. Even though the distillation cut points of two different naphthas are the same, the other properties such as PIONA may be different. If a naphtha is rich in aromatics content it is more economical to use the naphtha as a feedstock of an aromatics process instead of naphtha cracking process, and vice versa for the other case. The benefit which can be obtained by an optimal distribution of naphtha is shown as an example in Table 1. There may be many other examples for different products where we can extract more benefit by utilizing on-line property data such as freezing point and flash point of kerosene, cloud point or pour point of LGO and so on. Example of actual optimization result of SK #3 CDU plant is given in Table 2.

Table 1. LSR/Naph. Opt. With NIR data

Product		Opt.	Opt NIR	Flow Diff.	Value Diff.(M$/D)
LPG(CUM/Hr)		29.12	29.16	0.03	0.11
LSR (CUM/Hr)	Flow	78.06	80.98	2.92	-3.41
	n-P(%)	48.46	47.91		
H.Naph. (CUM/Hr)	Flow	81.04	88.04	7.0	74.81
	(N+2A)(%)	37.21	38.70		
Kero (CUM/Hr)		192.63	172.63	-20.0	-72.94
LGO (CUM/Hr)		225.21	237.46	12.25	42.07
A/R (CUM/Hr)		375.3	373.23	-2.08	-4.61
Total					36.03

Third, given the on-line NIR data the crude assay updating is improved and consequently performance of the other applications such as scheduling and planning can also be improved. Given more redundant measurements with property data, the data reconciliation and consequently the optimization become more reliable.

Finally, the on-line property data becomes a basis for an integrated optimization across refinery and petrochemical processes. Asshown in the example of LSR/Naphtha optimization, the yield of petrochemical processes is significantly affected by the quality of feed stock coming from refinery side. Simultaneous optimization of crude column cut-points and the yield of petrochemical processes can only be achieved when reliable on-line property data is available.

It will be a stepping step toward a perfectly automated plant where only one watching dog and one person to feed the dog live.

Table 2. An Example of actual optimization result

Products. Spec. & Operation Cond	Initial	Optimized	Spec.
LPG	26.88	26.57	
LSR	85.69	74.38	
RVP(Kg/cm2)	0.86	0.98	max 0.98
D95(C)	103.56	103	103 - 110
Naphtha	112.23	132.48	
D95(C)	144.39	145.98	130 - 150
Kerosene	186.07	171.35	
Freeze Pt. (C)	-47.19	-47.10	max -47.0
LGO	193.65	201.97	
D95(C)	361.93	360	350 - 360
HGO	1.0	1.0	
R/C	447.28	446.25	
Heater Outlet Temp. (C)	345.27	348.32	3.05
Top Pumparound A (KL/Hr)	349.65	319.65	-30
Top Pumparound B (KL/Hr)	539.55	489.55	-50
Kero Pumparound (KL/Hr)	144.17	164.17	20
LGO Pumparound (KL/Hr)	313.73	353.73	40
Total Economics (M$/D)	4630.4	4637.7	7.4

3.4 Examples of Real-Time NIR Data in Crude Distillation Unit

Examples of real-time NIR data in CDU are given in Fig.10 ~ 11. The examples are from No.3 CDU in SK Corporation's Ulsan Complex. You will actually be able to feel the performance of real-time NIR data.

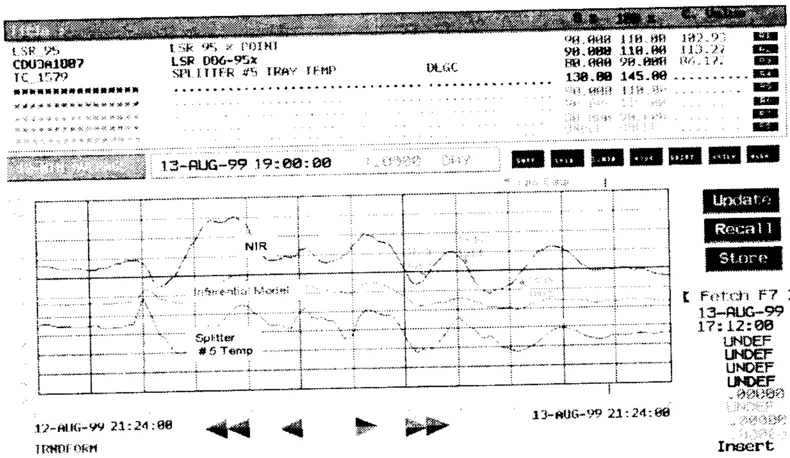

Fig.10. LSR D86 95%

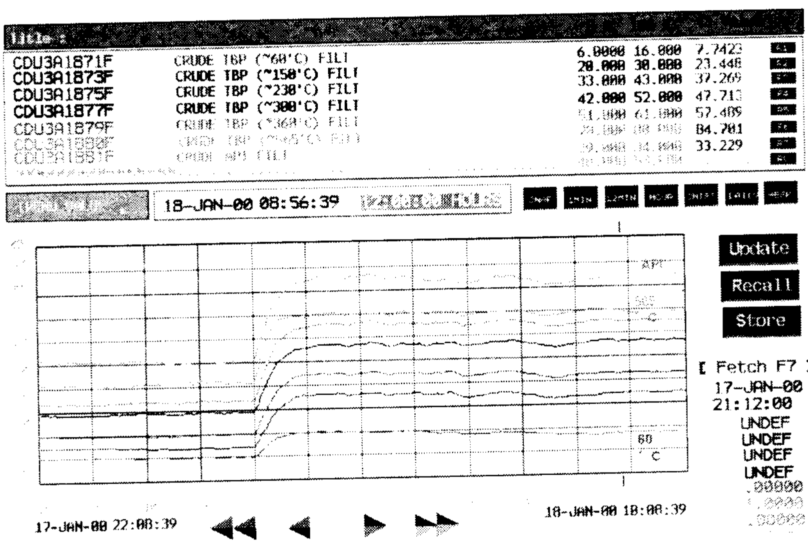

Fig.11. TBP & API Change of Crude Oil during Tank Switch

4. Other NIR Applications in SK Corporation

Since SK Corporation started studying the application of NIR into refinery and petrochemical processes, not only CDU but also many other NIR applications have successfully been completed and some projects are under progress currently. We do have NIR installed and being used satisfactorily in gasoline blending, diesel blending and UOP's xylene separation process. NIR application to lube base oil process and solvent process are under progress. Off-line NIR model development for naphtha cracker has been finished and we are waiting for the economic evaluation of its application in the process. Many analyzers in the laboratory have also been replaced with NIR and we could successfully decrease the laboratory workload significantly.