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PRACTICAL TROUBLESHOOTING IN THE FCC WITH CFD

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ABSTRACT

Fluid catalytic cracking (FCC) is an extremely complex process and, as a result, unit operators can encounter numerous costly and difficult FCC problems. COMSOL Multiphysics Computational Fluid Dynamics (CFD) software is used to troubleshoot the FCC process. The Port Harcourt Refinery Company (PHRC) plant was used as a case study. The ten-lump kinetic model was used in studying the hydrodynamics and yield in the FCC process. The results showed that application of COMSOL Multiphysics CFD software by an experienced FCC and CFD specialists, combining empirical data with theoretical models provides a powerful tool for successfully troubleshooting FCC problems.

Keywords: *CFD, FCC Problems, COMSOL Multiphysics, Kinetic Model, Troubleshooting*

INTRODUCTION

Modern refinery has many units. Fluid catalytic cracking unit (FCCU) is one of them and it is the workhorse of modern refinery. The FCCU reactor is one of the most complex equipment in the refinery. There are several types of this in the FCCU. Each type has several parts and is equipped with several internals such as cyclone separators and baffles [2, 3, 8]. Based on a refiner's need for increased conversion and selectivity for propylene production, Universal Oil Products (UOP) revamped an existing UOP Technology Management (TM) Stacked FCCU to include Optimix TM feed distributors, Visual-Spatial Short-Time Memory (VSSTM) riser disengaging and a modern reactor stripper design. The post-revamp operation has exceeded the process performance for propylene yield represented for the revamp. However, catalyst containment in the reactor was not as good as represented. A joint Risk Management plan was developed by UOP to identify all possible causes of the problem, establish the necessary means to allow for safe continued operation with the higher catalyst losses and the increased risk of erosion, and develop a long term solution. Considerable troubleshooting was performed to identify the root cause of the catalyst losses including gamma scans, tracer scans, X-ray imaging and physical testing of the catalyst in the main column bottoms. In addition, UOP's Engineering group reviewed design parameters, as-built equipment, and utilized computational fluid dynamic simulations. After the root cause analysis was complete, a risk/cost comparison was developed to arrive at the final solution. The resulting design modifications were engineered by UOP and installed by the refiner. The modifications have proven to be successful in eliminating the catalyst loss from the unit while preserving the yield performance [4]. Robert and other CFD specialists used CFD simulations to successfully troubleshoot the problem observed in the Carbon Heat fired (CHF) heater without costly expenses [7]. In this study, practical troubleshooting on the FCCU will be carried out to successfully correct difficult problems using COMSOL Multiphysics CFD software.

Predicting using CFD

Figures 1 to 3 show the predictions of the riser reactor pressure, temperature yield respectively using COMSOL Multiphysics for a ten-lump kinetic model [11]. Using the same procedure, the temperature and the yields of gasoline and coke can be predicted from figure 4 at the riser reactor height of 30m. The values predicted are shown in table 1. The temperature is 803.8K and the yield (wt %) of gasoline and coke is 49 and 6.25 respectively.

Troubleshooting using CFD

The CFD user makes use of the predicting ability of the COMSOL multiphysics in troubleshooting. The steps in troubleshooting are

(a) Stating the Problem

In troubleshooting, a problem will first be identified. For example in the FCC reactor riser, one can identify the problem of high coke yeild. For one to effectively diagnose the cause of a problem with a CFD code or software, experimental or practical work is very important and is a neccessity.

(b) Ascertaining the cause

A CFD modeling and simulation effort will be carried out as done elswhere to investigate and understand the cause of the high coke yield [9, 11]. In doing this one should

- Develop the baseline system using actual operating condition.
- Use the model for comparison among similar design.
- Use the model to test the effectiveness of physical modifications, in this case the input system.

The objective is to determine the effects of maldistribution of the inlet System and identify coke yields in the FCC riser. After using the CFD to predict the possible values, samples should be taken to the laboratory for analysis to see if the values correspond to each other. If they do not a problem has been identified. Then the problem is traced to know if it is as a result of the feed injection, catalyst flow problem, coke build up, improper design or any other problem. If the cause is as a result of low feed rate and low catalst oil ratio (COR), then The last stage is recommendation/remedy.

(c) Recommendation/Remedy

When once the cause is ascertained recommendations are made to remedy the the problem.

Materials

The average molecular weight, the thermodynamic properties of the feed, the plant operating conditions and the properties of the catalyst used in this study, the specific heat of different lumps and the kinetic parameters for cracking reactions are found elsewhere [5, 6, 2, 9, 10, 11].

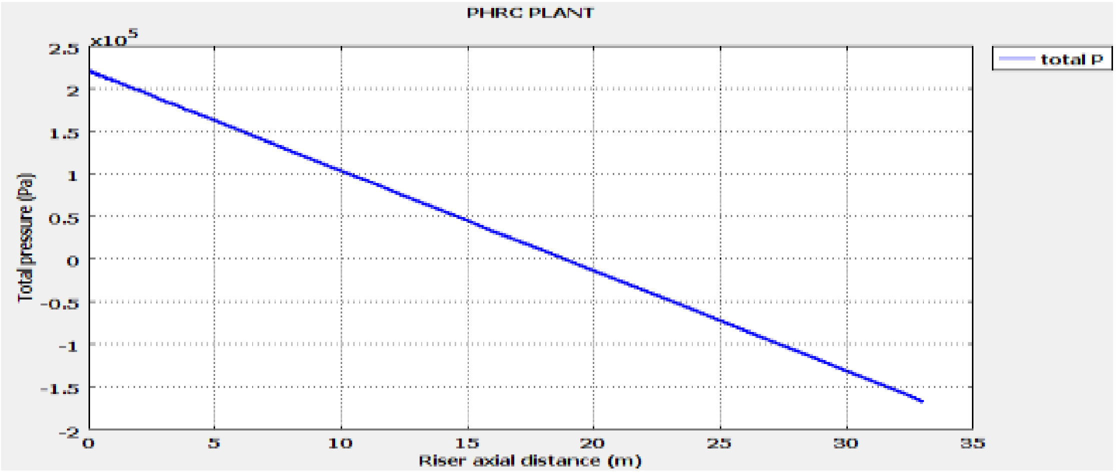

Figure 1. The pressure in the reactor riser versus riser axial distance

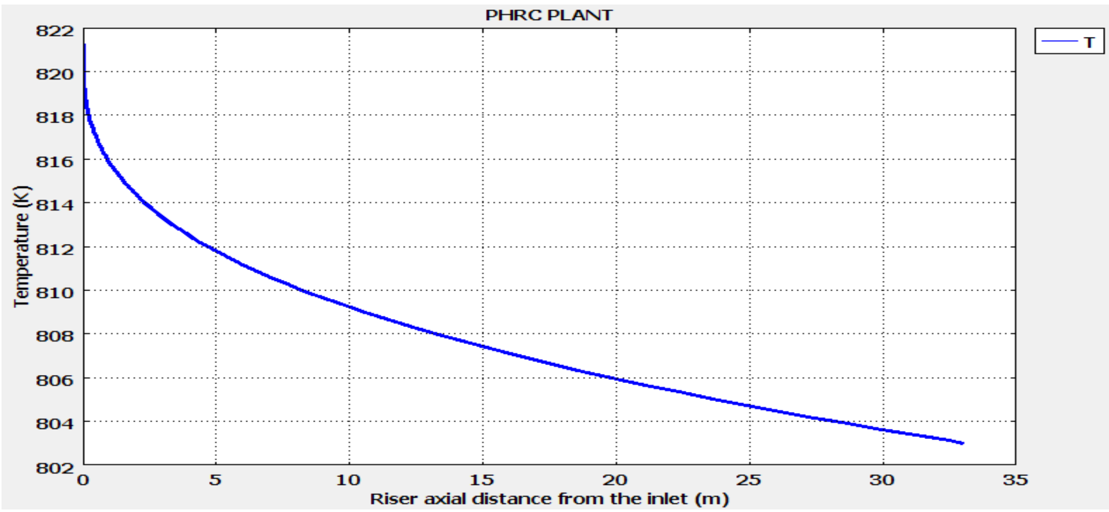

Figure 2. The temperature in the reactor riser versus riser axial distance

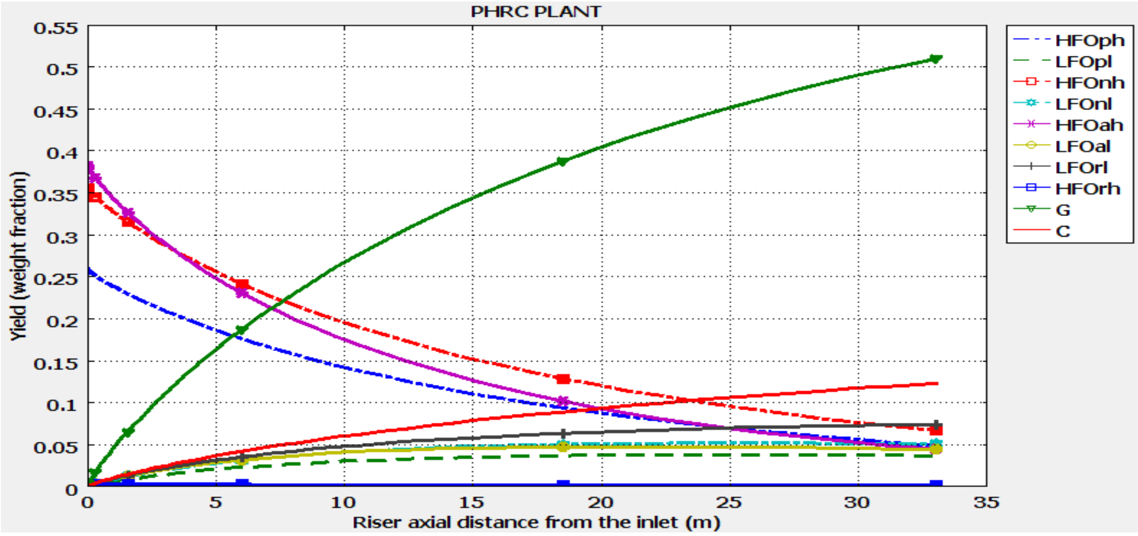

Figure 3. The yield in the reactor riser versus riser axial distance

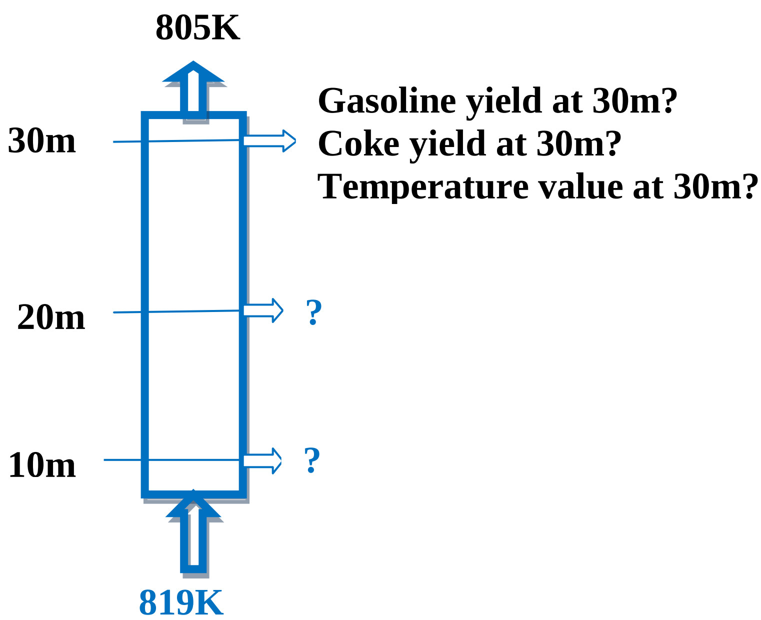

Figure 4: Predicting riser values at 30m

Troubleshooting a reported case in PHRC in 1995

Table 1: Predicted values at Riser height of 30m

	PREDICTED
Gasoline yield, (wt %)	49
Coke yield, (wt %)	6.25
Outlet Temperature, (K)	803.8

COMSOL Multiphysics can be used to troubleshoot and know the source of problems in the FCCU as follows:

(a) Stating the problem

Gasoline yield has fallen from 49.50% to 30% by weight.

(b) Condition of the plant when gasoline yied was 49.50% by weight

The industrial riser operating conditions of the PHRC plant are shown in table 2.

Table 2: Industrial riser operating conditions (PHRC Project, 1978)

Feed rate (kg/s)	30.87
Feed Quality (API)	D1298
COR (kg/kg)	7.04
Inlet pressure (kPa)	221
Feed temperature (K)	505
Catalyst inlet temperature (K)	1004
Steam (wt%)	5
Steam temperature (K)	464

(c). PHRCPlant data when gasoline yied was 49.50% by weight

These data are given in table 3

Table 3: PHRC Plant data when gasoline yield was 49.50% by weight

Feed rate (kg/s)	30.87
Feed Quality (API)	D1298
COR (kg/kg)	7.04
Inlet pressure (kPa)	221
Feed temperature (K)	505
Catalyst inlet temperature (K)	1004
Steam (wt%)	5
Steam temperature (K)	464
Gasoline yield (wt%	49.50
Coke yield (wt%)	5.90
Outlet riser temperature (K)	805

(d). Simulation data when gasoline yied was 49.50% by weight

The predicted values from the simulation of the riser reactor of the PHRC using COMSOL Multiphysics has been done when gasoline yeild was 49.50% and is shown in table 4.

Table 4: PHRC plant data, Predicted values from COMSOL Multiphysics

	PHRC PLANT DATA	PREDICTED VALUES
Gasoline yield, (% by wt)	49.50	51

Coke yield, (% by wt)	5.90	6.25
Outlet Temperature, (K)	805	803

(e) Available PHRC Plant data when gasoline yield has reduced to 30%

The available PHRC plant data when the gasoline yield has reduced to 30% is given in table 5

Table 5: Available PHRC Plant data when gasoline yield has reduced to 30%

Feed rate (kg/s)	30.87
Feed Quality (API)	D1298
COR (kg/kg)	?
Inlet pressure (kPa)	221
Feed temperature (K)	505
Catalyst inlet temperature (K)	1004
Steam (wt%)	?
Steam temperature (K)	464
Gasoline yield (wt%)	30
Coke yield (wt%)	1

(f) Noting possible causes for the reduction from 49.50 to 30% by weight of gasoline theoretically or from experience and using that as basis for further simulation using COMSOL Multiphysics

Some possible causes are

(i) The feed supply and catalyst supply valves may be faulty. This implies that the catalyst to oil ratio (COR) may have been changed due to the faulty valves.

(ii) The steam supply value may also be faulty.The weight percent of the steam that is feed to atomice the feed may also have been changed due to the faulty steam supply valve.

(iii) Cyclone may not be working properly.

(iv) etc.

(a) Start Simulation using COMSOL Multiphysics from the assumed possible causes to the unknown

(i) Keeping all the conditions the same and varying the COR in table 10

Since the yield of coke (1%) and some other conditions can be experimentally or otherwise determined apart from the COR and the wt % of the initial steam that was used when the yield of gasoline droped to 30% by weight as shown in table 5, we can troubleshoot by keeping all the conditions the same as in table 3 but varying the catalyst oil ratio (COR) until the simulation result of coke yield of 1% and a gasoline yield of 30% by weight is achieved. This is a trial by error method of troubleshooting.

Figure 5 shows coke yield of 1% and gasoline yield of 25% by weight when COR is 1.04. This implies that this simulation is not correct or in error since what we need is 1% by weight of coke and 30% by weight of gasoline.

Figure 6 shows coke yield of 1.5% and gasoline yield of 37% by weight when COR is 2.04. This implies that this simulation is also not correct or in error since what we need is 1% by weight of coke and 30% by weght of gasoline.

Figure 7 shows coke yield of 1.% and gasoline yield of 32% by weight when COR is 1.5. This implies that this simulation is also not correct or in error since what we need is 1% by weight of coke and 30% by weight of gasoline.

Figure 8 shows coke yield of 1% and gasoline yield of 29% by weight when COR is 2.04. This implies that this simulation is also not correct or in error since what we need is 1% by weight of coke and 30% by weight of gasoline.

Figure 9 and 10 shows coke yield of 1% and gasoline yield of 30% by weight when COR is 1.43. This implies that this simulation is correct since what we need is 1% by weight of coke and 30% by weght of gasoline.

Since the wt% of the initial steam supplied was not given in table 10, the same trial and error method was used until a coke yield of 1% and gasoline yield of 30% by weight was achieved as shown in figure 11.

From the simulation results it is very clear that coke yield of 1% and gasoline yield of 30% by weight could be caused by reduction of COR to 1.43 or increasing the steam inlet supply to 45.2% by weight. Since the feed rate is given in table 10, it will be assumed that the inlet catalyst supply valve is either faulty or the inlet steam supply valve is faulty and the operators will now be ordered for a thorough check. At the end if the two valves are working properly then the trobleshooting will be extended to the Feed valves and the cyclones and other possible causes (figure 12).

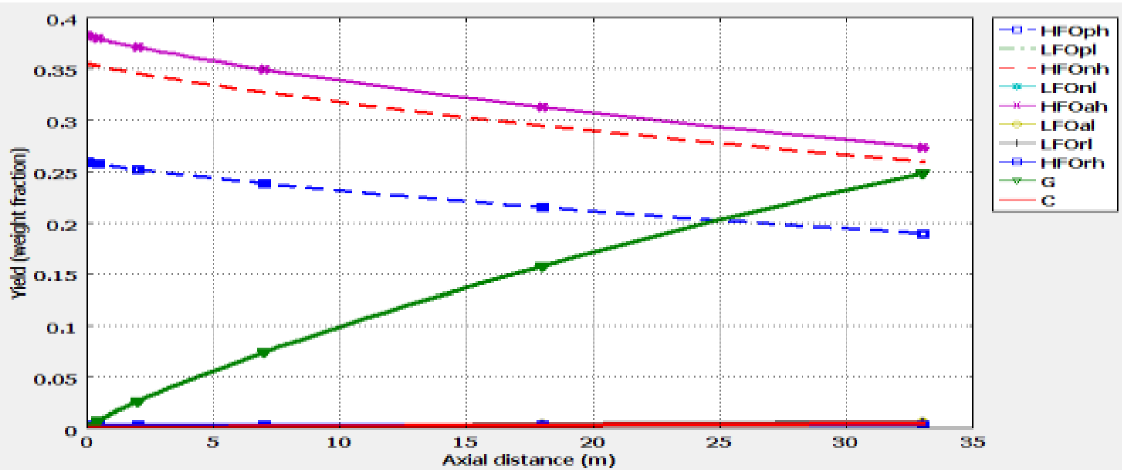

Fig 5. Gasoline and coke yields (COR is 1.04)

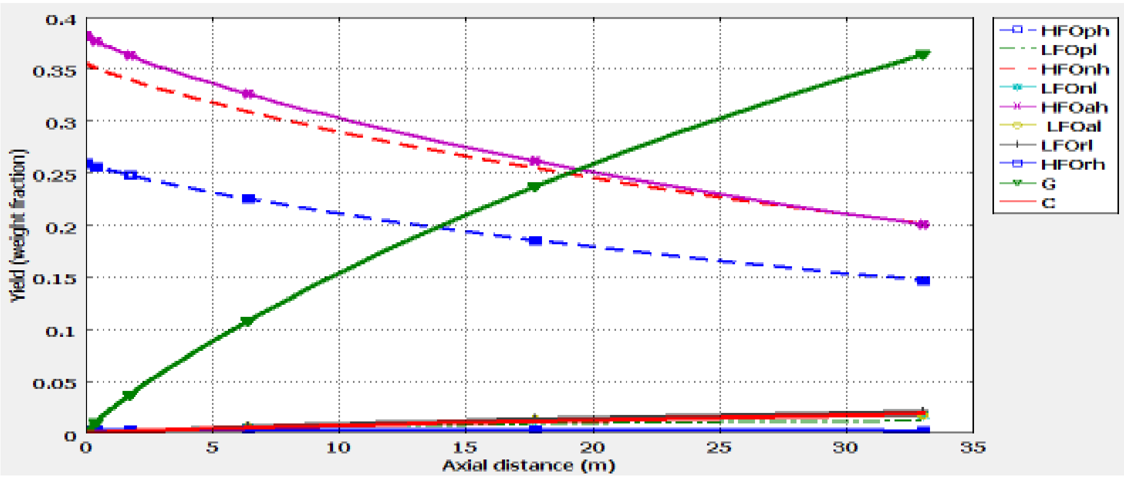

Fig 6: Gasoline and coke yields (COR is 2.04)

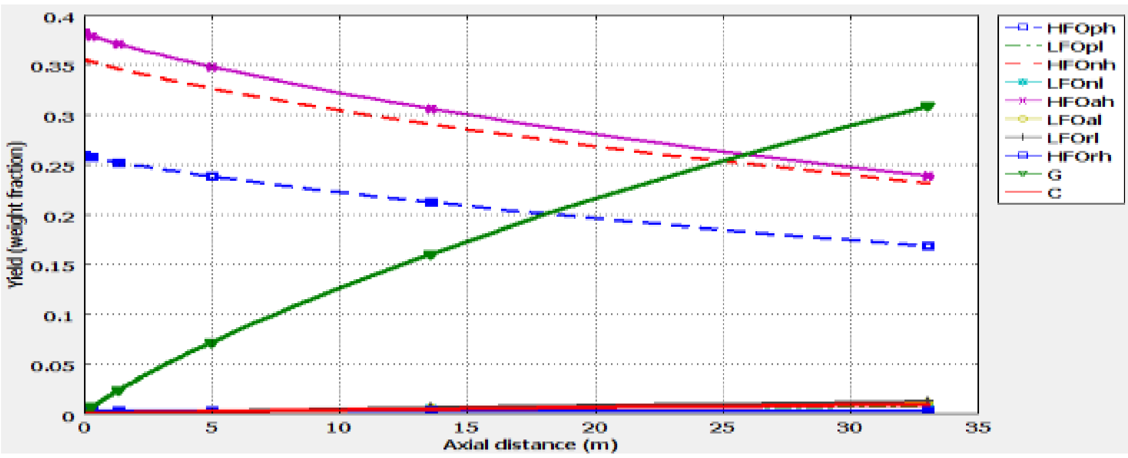

Fig 7. Gasoline and coke yields (COR is 1.5)

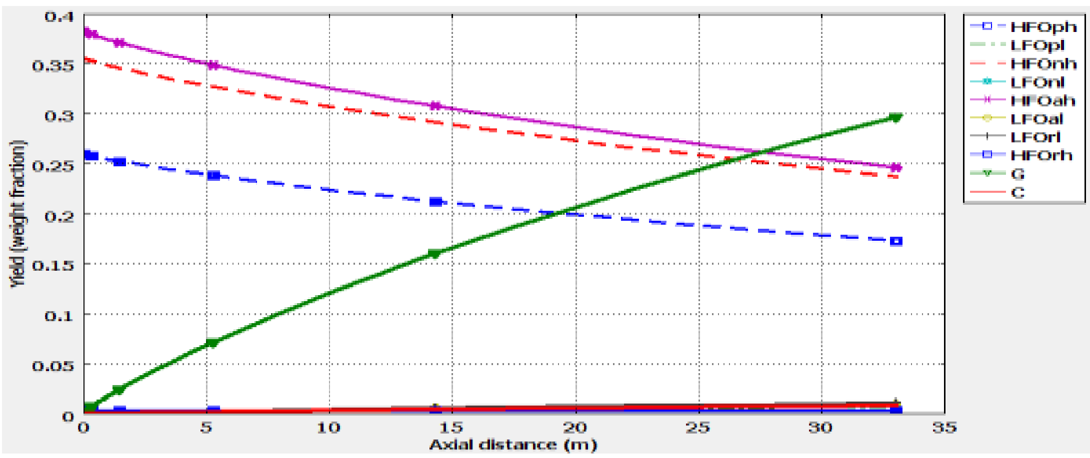

Fig 8. Gasoline and coke yields (COR is 1.4)

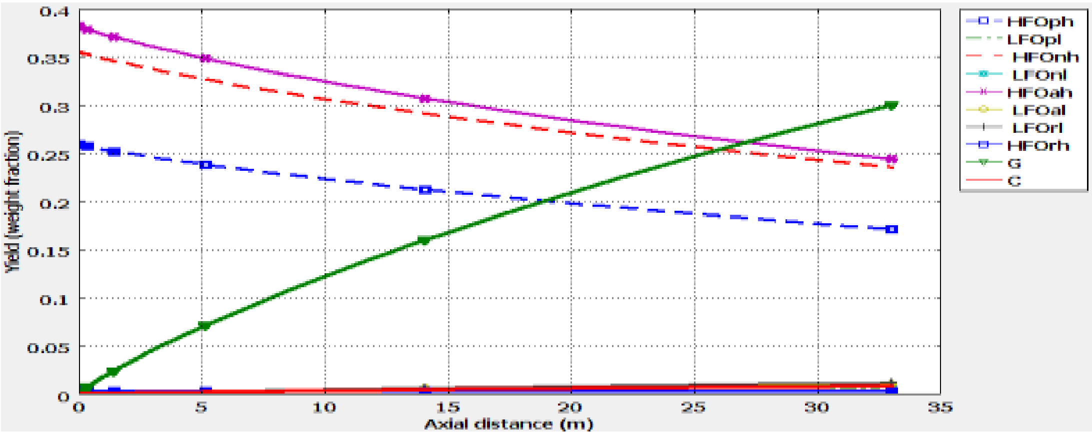

Fig 9. Yields versus riser axial distance (COR is 1.43)

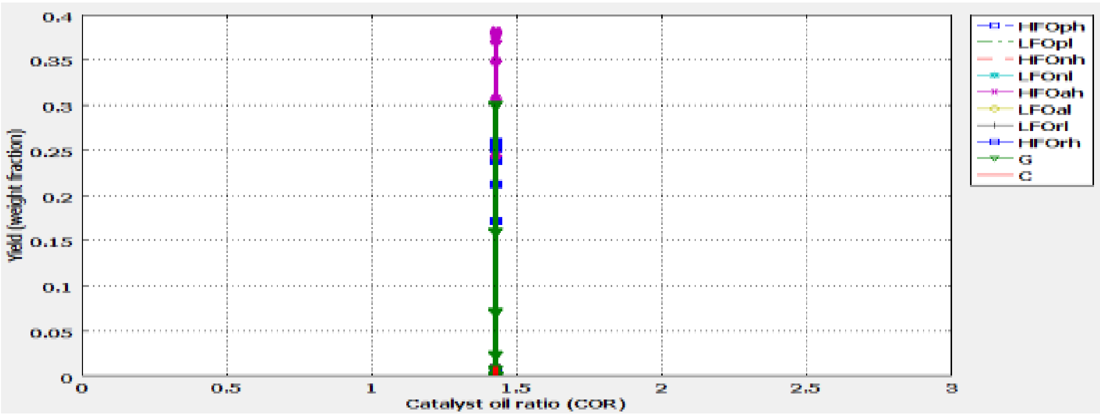

Fig 10. Gasoline and coke yields (COR is 1.43)

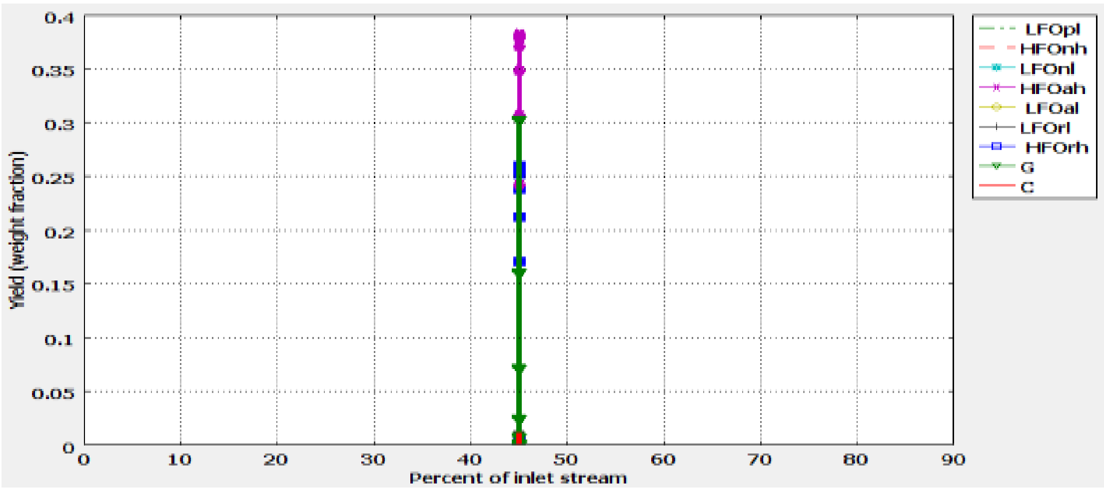

Fig11. Gasoline and coke yields (Percent of inlet steam is 45.2)

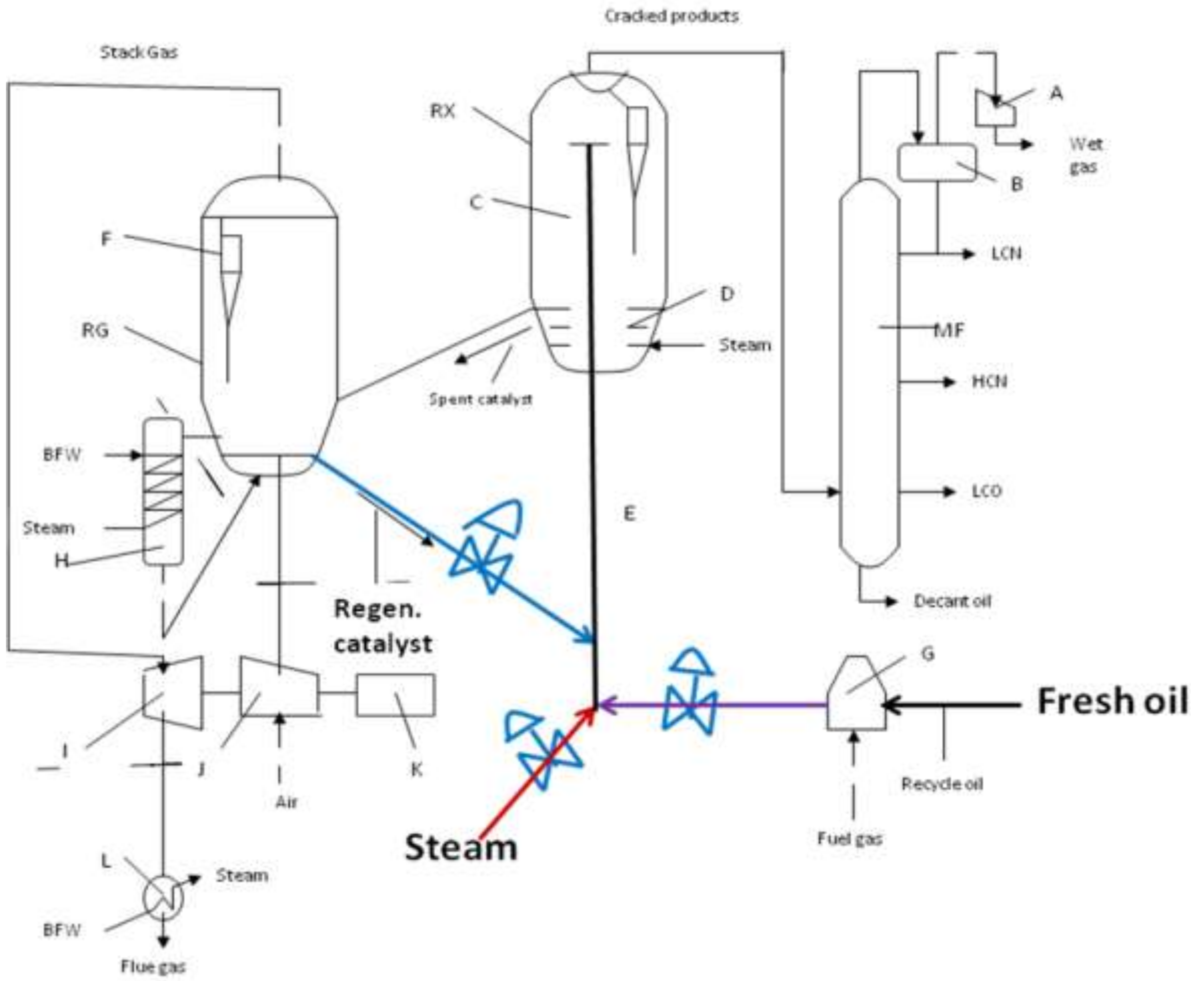

Fig 12. The checked parameters in troubleshooting. (RX) reactor; (RG) regenerator; (MF) main-fractionator; (A) wet gas compressor; (B) overhead drum; (C) disengager; (D) stripper; (E) reactor riser; (F) cyclones; (G) feed pre-heater; (H) catalyst cooler; (I) stack gas expander; (J) air blower; (K) motor; (L) CO boiler (or waste heat boiler) (PHRC Project, 1987).

CONCLUSION

Modern design and diagnostic tools such as CFD modelling can greatly reduce the risk associated with multiphase complex systems. When applied by experienced FCC specialists, empirical data combined with theoretical models provides a powerful tool for successfully troubleshooting costly emerging and avoidable problems.

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