



Comparative study of the optimum controller selection for control distillation column level in Khartoum Refinery

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ABSTRACT

The delayed coking unit in Khartoum Refinery is using cascade control technique for controlling the bottom level of the Coker fractionator, A temperature in the stripping section is held by steam to the reboiler. Situation may arise where the base level continues to drop even with the valve of the bottom flow is fully closed, this is due to the fact that the boil rate is greater than the liquid condensation rate which means that the rate of the steam to the reboiler is very high. It is required to control this critical situation by cascade control technique. MATLAB tool box consider as the main software used in the analysis the control loop of the delayed coking unit . The graphical user inter-phase (GUI) tool box helps in obtaining the transfer function for the coker fractionator which leads to complete analysis using Simulink in continuous, frequency domain and digital system. Unit Step applied to the transfer function which results in finding the final value = -0.02, the offset = -1.02 and settling time =7.71 sec. Different tuning methods were applied for the system to find the ultimate gain and Ziegler-Nichol table used for the recommended values. The roots locus method is preferable compared to other methods for the least deviation from the a average values which results in $K_c=0.15, \tau_I=1.3335\text{min}, \tau_D=0.33\text{min}$

Key words: Coker; Transfer function; Simulink ; Setting time; Frequency; Ultimate gain

INTRODUCTION

In chemical plants and petroleum refineries, there are, today, many distillation columns that are working well. There are also many others that are not working well, and at least a few that function very poorly, or not at all. Failure to obtain performance specified by the column design engineer is due, in many cases, to faulty or inadequate control system design. Troubleshooting of columns that are already in operation is frequently necessary, but practical considerations usually limit corrective measures to relatively minor items. Proper original design is by far the best way to guarantee satisfactory operation and control [1].

Therefore, we will approach the design of integrated distillation column control systems as a systems problem in process design. The application of feed forward, feedback, and protective controls will be coordinated with the sizing and proper location of process holdups [1].

The arguments in favor of advanced process control are known: Use of a complex relationship between controlled variables and manipulated variables in qualitative and quantitative ways, prediction capability of two to three hours, optimization potential, and reduced standard deviation permits operating closer to the limits [2].

1.1 The delayed coking process

The processing of low quality crudes is more frequent than ever and the heavy Feedstock is providing high quantities of vacuum residue. The delayed coking unit is the main converter of residue and usually a refinery that owns a Coker is considered to be residual free. Our work investigates the delayed coking process due to the new environmental conditions for end products and because economic optimization based on model advanced control is required for plant flexibility. During the last few years a new trend of processing heavy crudes appeared because of their prices and availability, despite all the problems generated by the procedure. The delayed coking is one of the few processes able to convert heavy products (atmospheric and vacuum residues) into lighter ones with high economic value: gases C1 – C3, gasoline, gas oil, heavy distillate and coke. [3], [4].

Figure 1 is a schematic representation of a delayed coking unit from a Khartoum refinery. The vacuum residue (1) represents the fresh feed (al-fula crude) which is heated up in the convection zone of the furnace (CF) at 315-320°C and then it is inserted at the bottom of the fractionator (F). Here, some lighter fractions are removed as side streams and the mixed feed from the fractionator’s bottom is redirected to the radiation section of the furnace (CF), where it is heated up to a high cracking temperature (490-495° C). In order to avoid the coke deposition on radiation tubes, high pressure steam is introduced in the furnace tubes. The outcome of the radiation section of the furnace is a partially cracked product which enters the coke drums (CD) where cracking continues. Each drum is filled with coke for approximately 20 hours, depending on the input flow and CCR (Conradson carbon residue). The remaining coke is periodically removed from the drum [3].

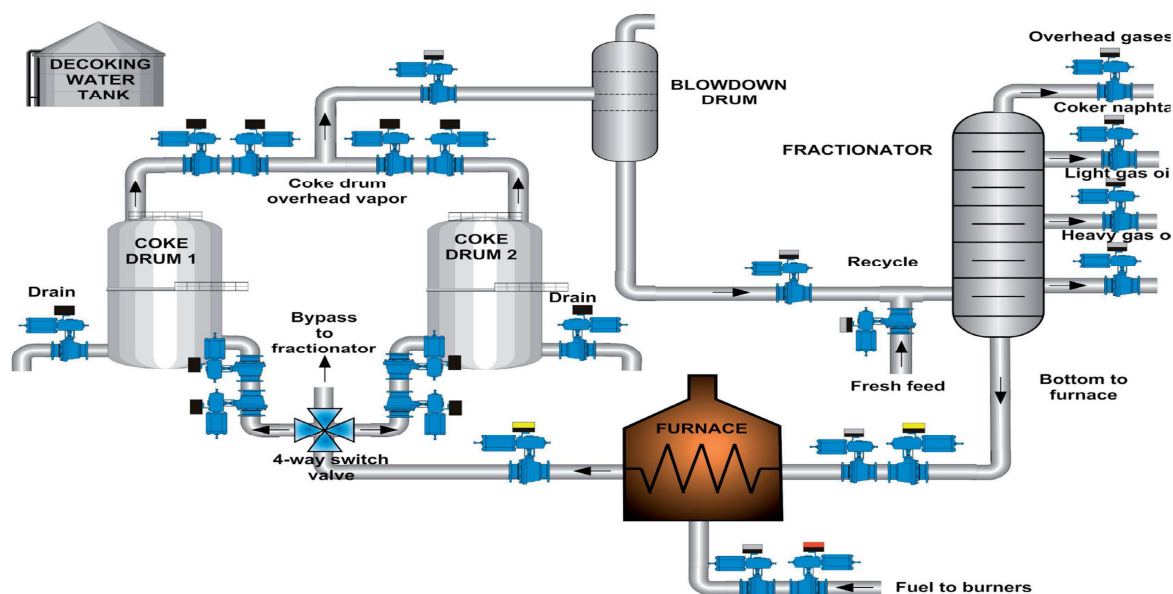


Figure 1: A schematic representation of a delayed coking unit

EXPERIMENTAL SECTION

Data were taken from Khartoum Refinery, the table below shows the corresponding values of bottom level of the coker’s fractionator and furnace flow rates

Table (1): Operating records for Column Bottom level& Furnace flow rate

Column bottom level%	Flow rate-convection(T/h)
65	114
65	114
69	113
68	112
68	112
50	112
50	113
50	113
45	113

2.1 Cascade control for fractionation column bottom level

The bottom level of the fractionation of the delayed coking unit (DCU) in Khartoum Refinery is the dominating control parameter and the convection flow of furnace is the secondary control parameter. The MATLAB tool box

via system identification by the graphical user interface (GUI) was used for predicating the model and the transfer function of the cascade control which considered as the key of the control system analysis and different tuning methods used for investigation the system stability[5],[6].

2.2 Transfer Function

The model developed using system identification tool box (Graphical user Interface GUI) from MATLAB helps for obtaining transfer function relates the bottom level against the furnace flow rates in the S-domain and in Z-domain [7],[8].

The Transfer function in Z-domain:

$$G_z = \frac{1.402z^2 - 0.1809z - 1.248}{z^2 - 0.1502z + 0.3614} \quad (1)$$

The transfer function converted using MATLAB commands into S-domain

$$G_s = \frac{1.402s^2 + 3.967s - 0.05113}{s^2 + 1.018s + 2.349} \quad (2)$$

2.2.1 Offset

Final Value:

$$C(\infty) = \lim_{s \rightarrow 0} s C_s \quad (3)$$

$$r(t) = 1.0 \quad (4)$$

$$R(s) = \frac{1}{s} \quad (5)$$

$$C_s = \frac{1}{s} \left(\frac{1.402s^2 + 3.967s - 0.05113}{s^2 + 1.018s + 2.349} \right) \quad (6)$$

$$C(\infty) = \lim_{s \rightarrow 0} s C_s \quad (7)$$

$$C(\infty) = \frac{1}{s} \left(\frac{1.402s^2 + 3.967s - 0.05113}{s^2 + 1.018s + 2.349} \right) \quad (8)$$

$$C(\infty) = -0.02$$

For the ideal response is unity .Hence

$$C_{id} = 1.0 \quad (9)$$

$$\text{Offset; } \varepsilon = C_{\infty} - C_{id} \quad (10)$$

$$\text{Offset} = -0.02 - 1 = -1.02$$

From the characteristic equation

$$0.43s^2 + 0.43s + 1 = 0 \quad (11)$$

Comparing with the characteristic equation

$$\tau = 0.66 ;$$

$$\tau \xi = 0.43,$$

So $\xi = 0.33$ and the system at this value is under damped.

The final value can be obtained from the graph due to unit Step. It is equivalent to calculated value.

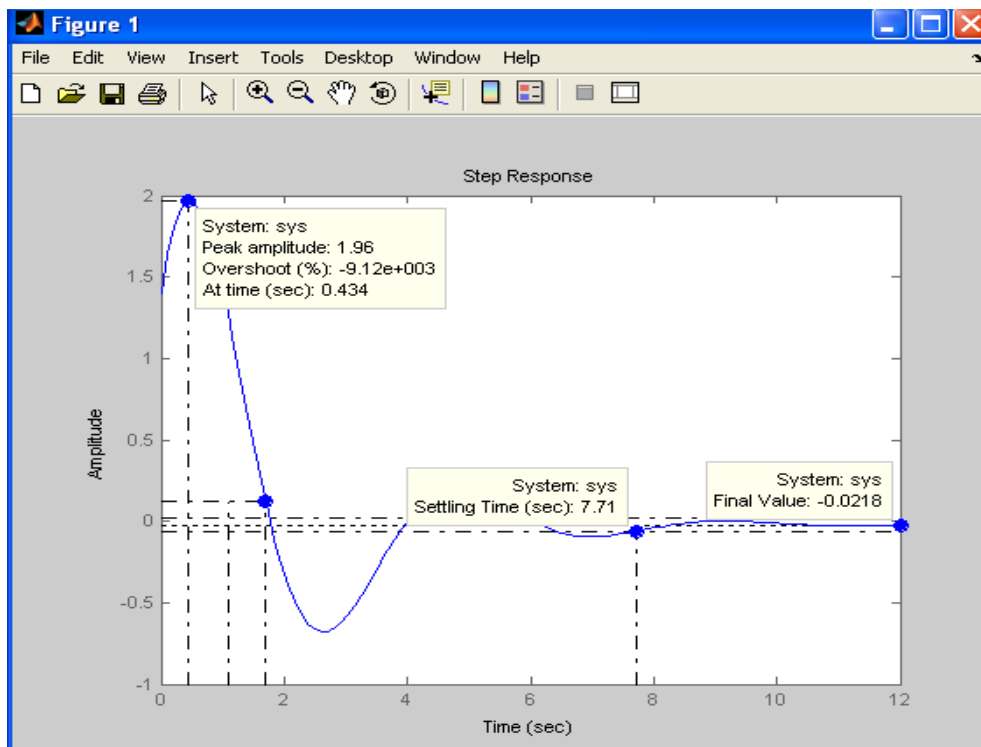


Fig. (2): Response of the system due to unit step

2.2.2 Tuning Methods

Tuning of the bottom level of the Coker’s fractionator investigated using different methods:

- a) Ziegler-Nichol b) Bode Criteria c) Nyquist Criteria d) Roots Locus and Routh Criteria

The Analysis using the previous methods illustrated in the figures below for determination the recommended gain [9].

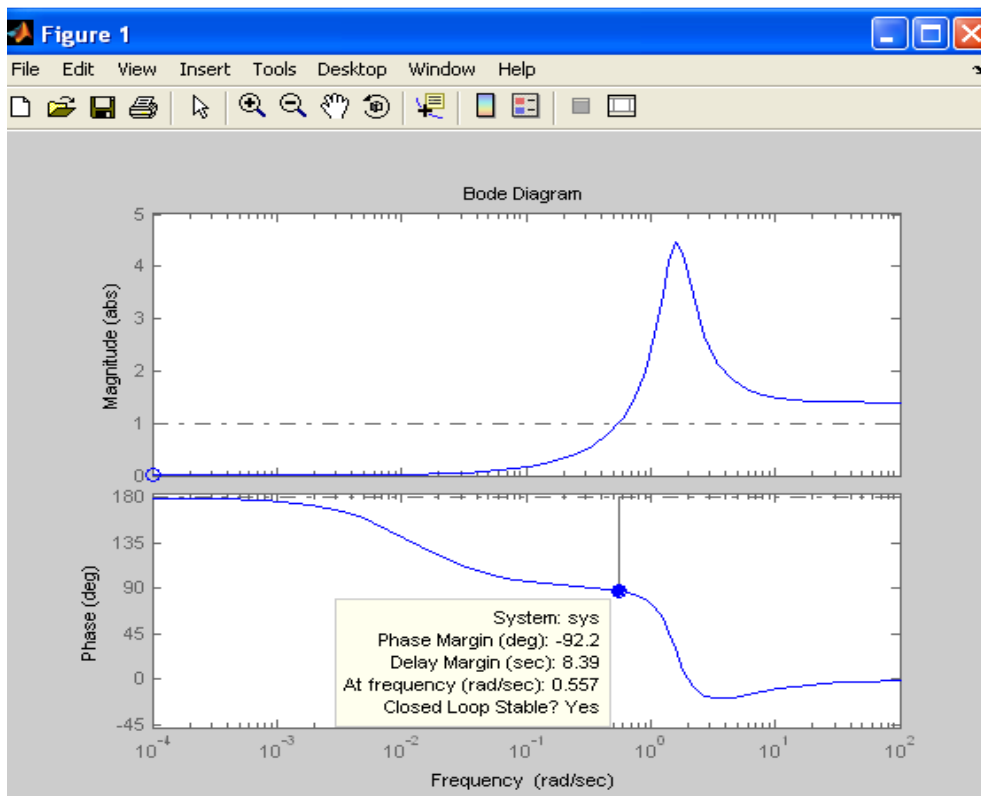


Fig.(3): Bode diagram for controlling bottom level

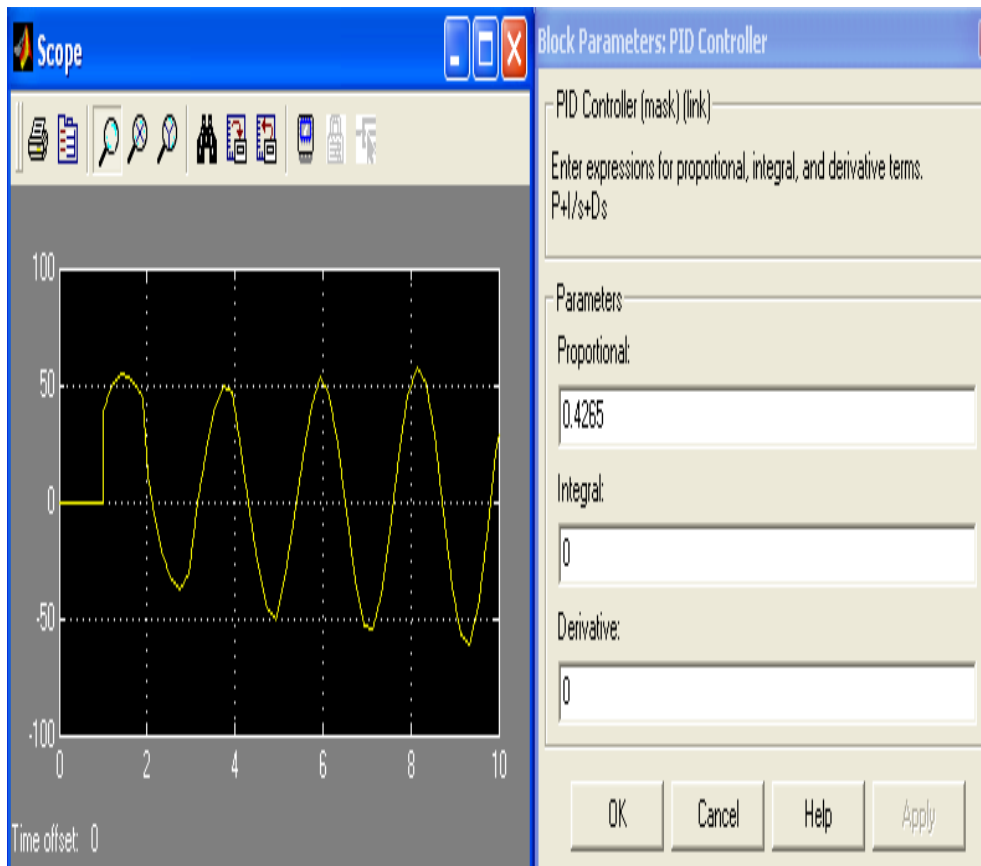


Fig.(4): Ziegler-Nichol for controlling bottom level

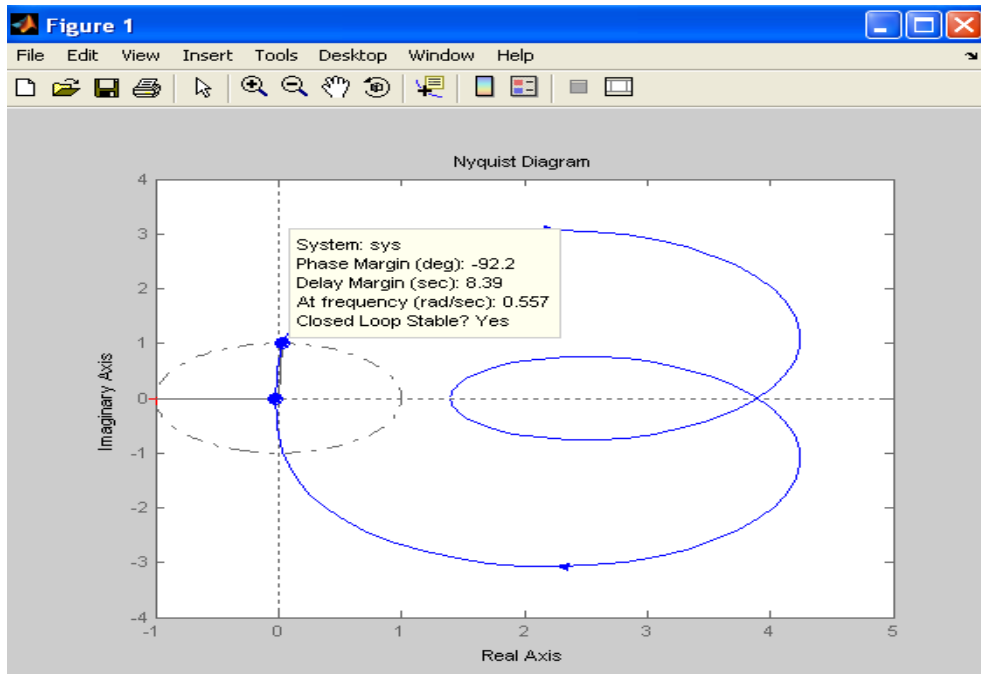


Fig.(5): Nyquist diagram for controlling bottom level

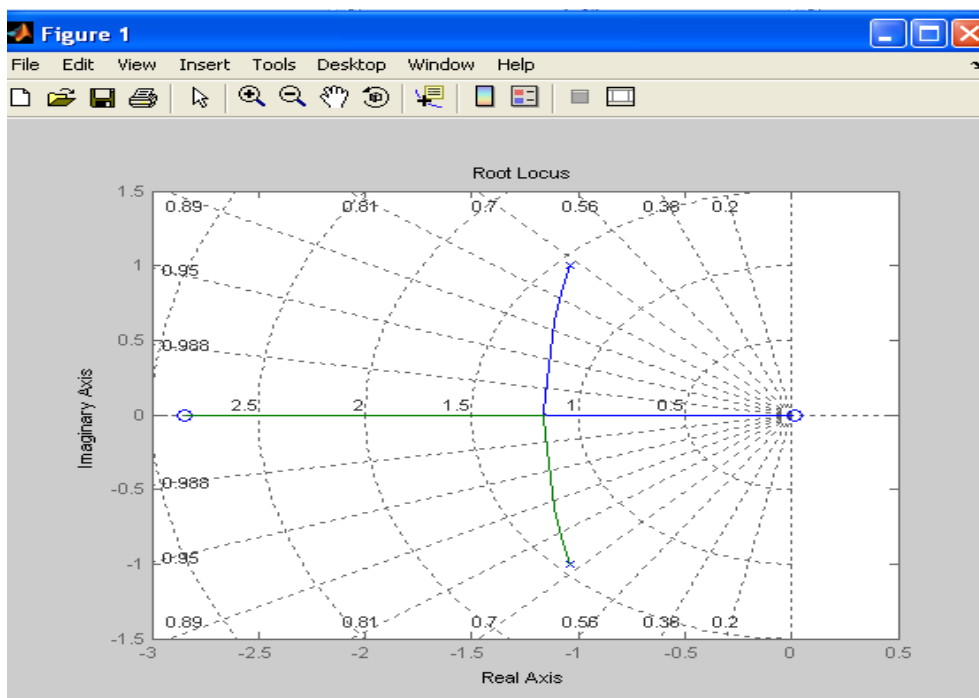


Fig.(6): Roots-Locus for controlling bottom level

RESULTS AND DISCUSSION

3.1 The results

The critical values were found using different analysis technique: Routh test, Nyquist, Bode and roots locus method. Then table 1 used to find the gain and integral time and derivative time for different types of controller suggested.

Table 1: Z.N recommended setting for feedback controller

Controller	K_c	τ_i (min)	τ_D (min)
P	$k_u/2$	—	—
PI	$k_u/2.2$	$P_u/1.2$	—
PID	$k_u/1.7$	$P_u/2$	$P_u/8$

Table (2): Comparison between Ziegler- Nichols ,Bode, Nyquist, Roots Locus and Routh methods

Method		K_c	τ_i	τ_D
Ziegler-Nichols	P	0.21	-	-
	PI	0.19	3.33	-
	PID	0.25	2	0.5
Bode Method	P	0.98	-	-
	PI	0.88	9.39	-
	PID	1.18	5.64	1.4
Nyquist Method	P	0.98	-	-
	PI	0.88	9.39	-
	PID	1.18	5.64	1.4
Roots Locus	P	0.125	-	-
	PI	0.1125	3.87	-
	PID	0.15	2.3	0.575
Routh Criteria	P	0.125	-	-
	PI	0.1125	2.25	-
	PID	0.15	1.335	0.33

Table (3): Deviation values of proportional gain from average values for P-

Method	K_c	$ K_c - k^*_{cl} $
Ziegler-Nichols	0.21	0.28
Bode Method	0.985	0.49
Nyquist Method	0.985	0.49
Roots Locus	0.128	0.36
Routh Criteria	0.125	0.37
Average Value	$K^*_c=0.49$	

Table (4): Deviation from average values for PI-Controller

Method	k_c	K_c-k^*c	τ_i	$ \tau_i - \tau^*_i $
Ziegler-Nichols	0.19	0.24	3.3	2.34
Bode Method	0.88	0.45	9.39	3.75
Nyquist Method	0.88	0.45	9.39	3.75
Roots Locus	0.11	0.32	3.87	1.77
Routh Criteria	0.11	0.32	2.25	3.39
Average value	0.43		5.64	

Table (5): Deviation values of Constant time from average values for PID

Method	K_c	K_c-k^*c	τ_i	$ \tau_i - \tau^*_i $	τ_d	$ \tau_d - \tau^*_d $
Ziegler-Nichols	0.25	0.33	2	1.38	0.5	0.06
Bode Method	1.18	0.60	5.64	2.26	1.4	0.84
Nyquist Method	1.18	0.60	5.64	2.26	1.4	0.84
Roots Locus	0.15	0.45	2.3	1.08	0.58	0.02
Routh Criteria	0.15	0.45	1.33	2.05	0.33	0.23
Average value	0.58		3.38		0.56	

3.2 Discussion

The root locus method is a very useful graphical technique for identifying the roots of the characteristic equation:

The roots locus method result is the minimum deviation compared to other different methods. The deviation using PID controller for the proportional gain = 0.45 from the average value, the deviation in the integral time=1.08 from the average value and the derivative time =0.02 from average value.

CONCLUSION

From an economic point of view, the delayed coking process is a valuable solution to the problem of decreasing residual fuel demand. It also generates a variety of fuels and in some cases a considerable amount of high quality coke (needle while eliminating environmentally unfriendly streams that often involve a disposal cost. Implementing advanced process control on a coking plant is quite a difficult task but the results could be remarkable: energy savings, maximized throughput, decreased CO emissions and improved yields while increasing the overall profit of the refinery.

Recommendation

The application of the override is essential for controlling the base level so recommend to adopt override control especially for the base level due to dangerous situation when the level goes below the set point which leads to dry the column, further the control protect the column from this situation.

The roots Locus method is preferable method for tuning and controlling base level of the coker's fractionator.

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