COMPUTATIONAL MODELLING OF HEAT EXCHANGE IN A FLUIDIZED BED BIOMASS GASIFIER APPLYING FOURIER TRANFORMS

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Abstract. *Agricultural wastes, and most generally biomass, represent attractive potential feedstock to sustainable energy production. The electricity energy production from biomass offers an environmentally friendly alternative to use of fossil fuel. A biomass fuelled integrated gasification/ gas turbine (BIG/GT) process has the promise of being able to produce electricity with a high efficiency and low emissions. Amongst diverse types of biomass, cane bagasse wastes are a great option to substitute fossil fuel, mainly in Brazil because of their abundance. However, bagasse due to its fibrous nature, low bulk density and high moisture contents is a difficult fuel and cannot be used directly in fluidized bed combustion, which is actually one of the more efficient method to convert biomass to energy. A valid alternative is the gasification technology. Gasification is, in fact, a thermochemical process in which solid/liquid fuel is converted in fuel gases. The gas-solid fluidized bed gasification presented in this present paper involves a gaseous phase and a solid phase. The modeling dynamic has been made through of energy balances for both gaseous and solid phases, forming, thus, a coupled partial differentiate equation system (PDEs). The implementation of the transformed of Fourier to system of PDEs, transforms it in a coupled ordinary differentiate equation system (EDOs). Several papers in the literature show the solution of these equations with the use of numerical technique such as line method. However it takes a long running time and can become the unviable process. On the one hand, this new technique is a hybrid technique that speed up the computational time to get the states variables. At last, the EDO system was solved using the method of Runge Kutta Gill by mean of software MATLAB 7.1*

Keywords*: Energy's balance, Fourier Transforms, Gasifier, Runge Kutta Gill.*

1. INTRODUCTION

Dependence on fossil fuels as the main energy sources has led to serious crisis and environmental problems, i.e. fossil fuel depletion and pollutant emission. The increasing energy demands will speed up the exhaustion of the finite fossil fuel. Moreover, combustion of fossil fuel produces substantial greenhouse and toxic gases, such as CO_2, NO_2, NO_x and other pollutants, causing global warming and acid rain.

Continuous effort has made been in exploration of clean, renewable alternatives for a sustainable development. Biomass is one of the most abundant renewable resources. (FILIPPISA et. al., 2005).

Biomass had been used for centuries. Currently, biomass contributes about 12% of today's world energy supply, while in many developing countries it contributes 40-50% energy supply. Biomass researches are recently receiving increasing attention because of the probable waste to energy application. For instance, 150 GT of vegetable bio-matter generated globally every year can produce about 1.08×10^{10} GJ energy. (MENG NI et. al., 2006).

It is traditionally used as fuel to satisfy the heat and electricity demand of the processing, but this conversion is generally achieved with low conversion efficiency. Bagasse could also be used for the production of biofuel (ethanol). However, processes involving bagasse for ethanol production needs a hydrolysis step, which requires the use of large amount of cellulases enzymes of saccharification or treatments with strong acids either concentrated or diluted. Both process gives rise to some interest but they do not show economic feasibility at present. Hence further efforts should be made for finding new routes achieving it.

A cost effective and environmentally compatible energy use of bagasse requires newer technologies compared to the conventional technologies stokers-fired combustors. However bagasse due to its fibrous nature, low bulk density and high moisture content is a difficult fuel and can not be used directly in a fluidized bed combustor apparatus, which is actually one of more efficient method to convert biomass to energy. Furthermore, the low density is often cause of entrainment phenomena in the reactor.

A valid alternative to bagasse combustion process is represented by gaseification technology. Gasification is, in fact, not only claimed as an environmental clean process, but also appears to offer of the one of the most attractive technology in the biomass conversion for the energy production. (DERMIBAS et. al., 2001).

Fluidized bed gasifiers have been used to converting agricultural wastes, such as biomass, into energy. The advantages of fluidized bed reactors include: good gas solid contact, excellent heat transfer characteristics, better temperature control, large heat storage capacity, good degree of turbulence and high volumetric capacity. The existing of fluidized bed gasification models can be classified as thermodynamics models, flow regime models and transient models. (SADAKA et. al., 2002)

The aim of this work was to develop a comprehensive model capable of describing the fluidized bed biomass gasification phenomenon specifically to energy balance. So, the model must be capable of predicting the temperature distribution of each species in the vertical direction of the bed.

The computational modeling of heat transfer in a fluidized bed biomass gasifier involves thermal convection, thermal dispersion and exchange among solid and liquid phase's effects.

The gasifier has a solid phase (bagasse) and a gas phase (air). The solid phase is inserted laterally in the fluidized bed and the air is inserted in reactor bottom. The air is injected by means of one air compressor and, then, it is distributed for a deliverering plate in all the stream of fluidized bed. So the mixture, with aid of an initial flame, initiates the process of gasification. Thus, there are three zones inside of bed. The first is one of combustion, where the fixed carbon from biomass reacted with O_2 from air. This area reaches, approximately, 960 – 1340°C, which just serves to supply heat in the other zone. This other zone is the zone of reduction that keeps itself among a temperature of 800 – 960°C and in it is produced the fuel gases. The last zone is called of freeboard zone, which happened desvolatilization and drying of final products. The figure 1 shows a prototype simplified of the fluidized bed gasifier that will be used for the simulation of this paper.

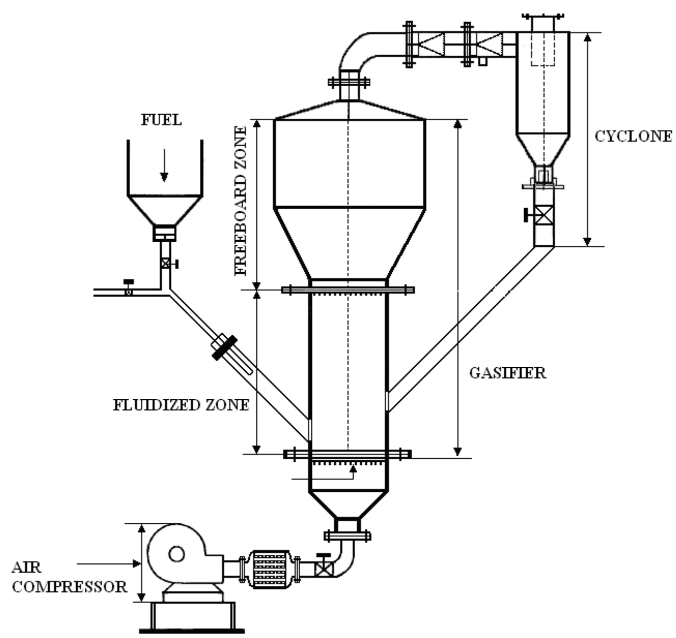

Figure 1: Schematically diagram of fluidized bed gasifier.

The problem can be to solve using common numerical techniques such as line method, but it takes a long computational time. However, we are able to minimize this time using a new analytical-numerical technical called of Fourier transforms. The implementation of this method to systems of PDE's, transforms it in a coupled ordinary differential equation systems (ODE's). The system of ODE's was solved by means of method of Runge Kutta Gill, using Matlab® 7.1. The application of this mathematical technique allows quantifying variable to the problem in low computational time. The answers of this variable, then, allow us to make a sensibility analysis in order to check the influence of the operational parameters of inlet in low computational time too. This is a great tool to process control.

2. MATEMATICAL MODEL DESCRIPTION

The mathematical modeling acts of significant form to explain the behavior of the temperatures in the both gaseous and solid phases. In this paper, energy balance equations assumption the follow restrictions: the referring equation the gaseous phase only involves thermal accumulation term, convection, thermal dispersion and exchange between solid-gas, while, the equation linked to solid phase only have the accumulation term and exchange between solid-gas. Thus:

- Energy balance to the gaseous phase:

$$\frac{\partial T_g}{\partial t} = \frac{K_{eg}}{\varepsilon C_{pg}\rho_g}\frac{\partial^2 T_g}{\partial z^2} - V_g\frac{\partial T_g}{\partial z} - \frac{h_p a}{\varepsilon C_{pg}\rho_g}\left[T_g - T_p\right] \quad (1)$$

- Initial condition

$$T_g\Big|_{t=0} = \delta(z - z_0) \quad (2)$$

- Energy balance to the solid phase:

$$(1-\varepsilon)\frac{\partial T_s}{\partial t} = \frac{K_{ep}}{C_{pp}\rho_p}\frac{\partial^2 T_p}{\partial z^2} + \frac{h_p a}{C_{pp}\rho_p}\left[T_g - T_p\right] \quad (3)$$

- Initial condition

$$T_p\Big|_{t=0} = \delta(z - z_0) \quad (4)$$

2. IMPLEMENTATION OF THE FOURIER TRASFORMS.

The system showed in this paper was solved using the Fourier transforms. The equations (1) and (3) can be approached through Fourier's series in sine, according to following forms:

$$T_g = \sum_{n=1}^{N} b_{ng}(t)sen\left(\frac{n\pi}{L}\right)z \quad (5)$$

$$T_s = \sum_{n=1}^{N} b_{ns}(t)sen\left(\frac{n\pi}{L}\right)z \quad (6)$$

This approaching is derivate once in time, once and twice in position. So, they are introduced in the equation (1) and (3), transforms it in a coupled ordinary differentiate equation system. Just like below:

$$\frac{db_{jg}}{dt} = \beta_1 b_{jg} + \beta_2 b_{js} \quad (7)$$

$$\frac{db_{js}}{dt} = \beta_3 b_{js} + \beta_4 b_{jg} \quad (8)$$

Where:

$$\beta_1 = -\left(\frac{K_{eg}}{V_g\varepsilon C_{pg}\rho_g L}\right)\left(\frac{j\pi}{L}\right)^2 - \left(\frac{j\pi}{L}\right)\cot g\left(\frac{j\pi}{L}\right)z - \frac{haL}{\varepsilon C_{pg}\rho_g V_g} \quad (9)$$

$$\beta_2 = \frac{haL}{\varepsilon C_{pg}\rho_g V_g} \quad (10)$$

$$\beta_3 = -\left(\frac{K_{ep}}{V_s(1-\varepsilon)C_{ps}\rho_s L}\right)\left(\frac{j\pi}{L}\right)^2 - \frac{haL}{(1-\varepsilon)C_{ps}\rho_s V_s} \quad (11)$$

$$\beta_4 = \frac{haL}{(1-\varepsilon)C_{ps}\rho_s V_s} \quad (12)$$

The equation(7) and (8) was solved using the Runge Kutta Gill method. By the way, it was developed one program using the Matlab software to solve this equations.

3. DISCUSSION AND RESULTS:

In this section, results from the model are presented. The solving of the model give us the behavior of the temperatures profiles of solid and gaseous phase. Their behaviors had shown to the process of heating and cooling of the gaseous and solid phases, respectively. The data used in this simulation are showed in the table 1 below:

Table 1: Parameters used in simulation (FAN et. al., 2003; INCROPERA et. al., 1996)

Symbols	**Names**	**Values / units**
ρ_g	Gas Density	24, kg/m^3
ε	Bed's Porosity	0.65
a	Interfacial area	150, m^{-1}
V_g	Gas superficial velocity	0.625, m/s
V_s	Solid superficial velocity	0.28, m/s
μ_g	Gas viscosity	4.244× 10^{-5}, Pa·s
ρ_s	Solid density	1350, kg/m^3
C_{pg}	Gas specific capacity	4.178, J/kg·K
C_{pp}	Solid specific capacity	1260, J/kg K
K_{eg}	Thermal conductivity of gaseous phase	6.67 × 10^{-2}, W/m K
K_{ep}	Thermal conductivity of solid phase	4.5× 10^{-2}, W/m K
d_p	Particle diameter	183.5, µm

To maintain a given temperature level in the bed, we need to consider a definite amount of heat by with an appropriate heat exchange surface. Consequently, quantitative information on the heat transfer coefficient between surface and bed is needed for the rational design of fluidized bed gasifier. The calculus of this coefficient s been made using the follow correlation (SYAMLAL et. al.,1993):

$$Nu = \left(7 - 10\cdot\varepsilon + 5\cdot\varepsilon^2\right)\left(1 + 0.7\cdot \mathrm{Re}^{0.2}\, \mathrm{Pr}^{1/3}\right) + \mathrm{Re}^{0.7}\, \mathrm{Pr}^{1/3}\left(1.33 - 2.4\cdot\varepsilon + 1.2\varepsilon\right) \quad (13)$$

Where:

$$\frac{1}{h} = \frac{1}{h_s} + \frac{1}{h_g};\ h_g = \frac{K_{e,g} Nu}{d};\ h_p = \frac{K_{e,p} Nu}{d};\ \mathrm{Pr} = \frac{C_{p,p}\mu_g}{K_{e,g}};\ \mathrm{Re} = \frac{d_s\left|V_g - V_s\right|\rho_g}{\mu_g} \quad (14)$$

One of the remarkable features of the fluidized bed is its temperature uniformity, with effective thermal conductivities up to one hundred times that of silver. In practice, this uniformity exists in both radial and axial directions, even in bed 10 m in diameter. This high rate of heat transfer is due to the bubble-induced circulation of solids. This ability of a fluidized bed gasifier to maintain close to isothermal conditions makes it attractive for a variety of reaction, especially exothermic reactions with high rates of heat release such as gasification.

The figure 2 shows the temperature profile of the solid phase in a fluidized bed gasifier.

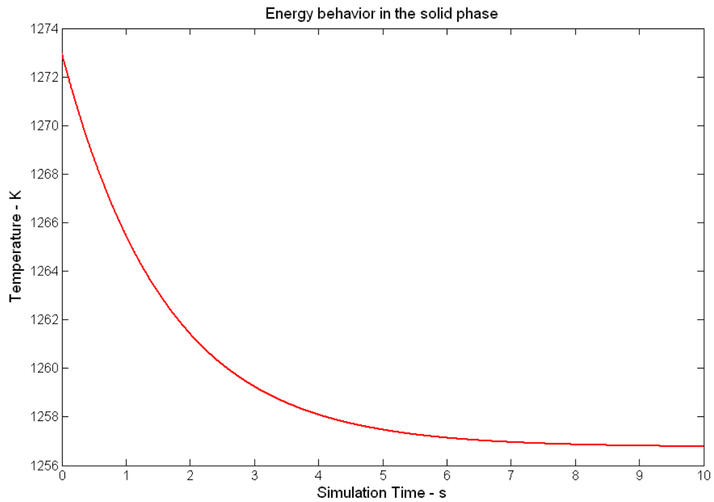

Figure 2: Temperature profile in the solid phase.

The figure 3 shows the temperature profile of the solid phase in a fluidized bed gasifier.

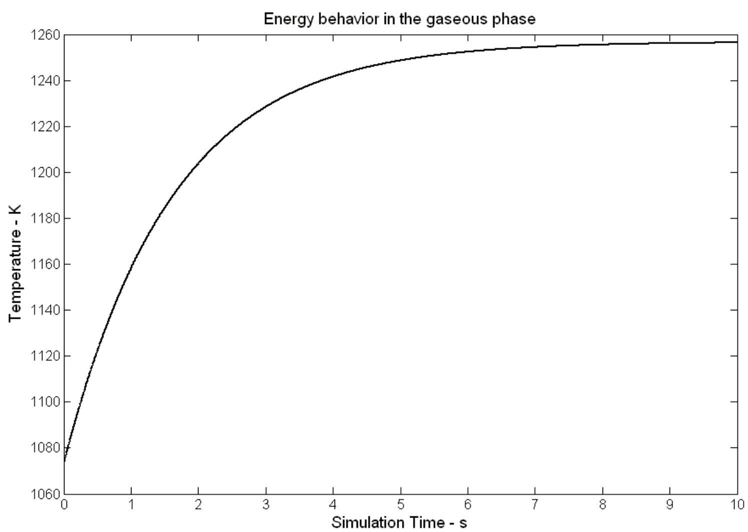

Figure 3: Temperature profile in solid phase.

There is growing up to the temperature in the gaseous phase, while, to the solid phase, can see a decrease of it. Furthermore, the growing up in the gaseous phase is greater than the decrease in the solid phase, because there is a biggest value of the calorific capacities and thermal conductivity in the gaseous phase.

It was analyzed the temperature profile in fluidized bed gasifier to several kinds of porosity. The porosity is a measure of void spaces in a material, and it measured as a fraction, between 0 – 1. In this case, variations has been made to values of porosity between 0.05 – 0.85. Then, it was seen that than less porosity inside of gasifier, better exchange and faster the temperature is stabilized. The figure 4 shows this:

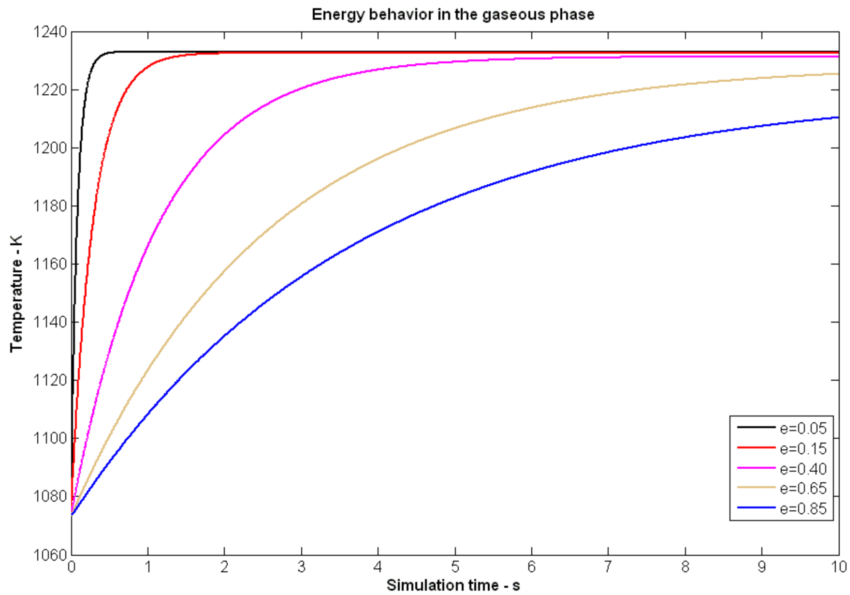

Figure 4: Temperature profiles of several kinds of porosity .in gaseous phase

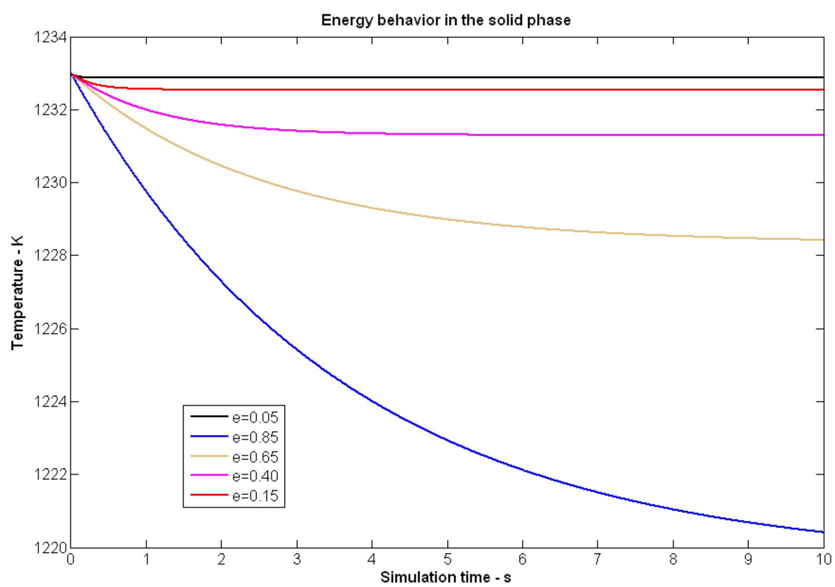

Figure 5: Temperature profile of several kinds of porosity in solid phase

Other parameter very important must be analyzed. It can be seen that the interfacial area has remarkable influence on temperatures profiles. The interfacial area facilities the reaction becoming faster the stabilization, as it can see in the figure below.

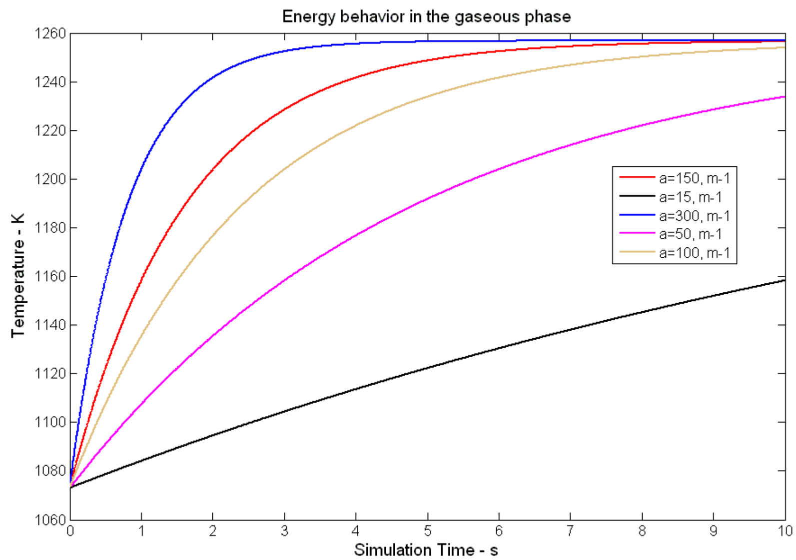

Figure 5: Temperatures profiles to the gaseous phase in several kinds of interfacial area.

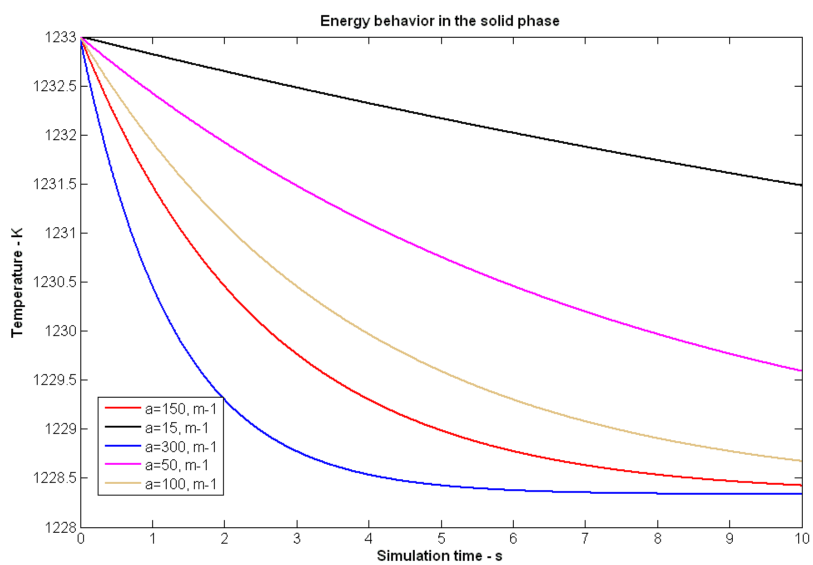

Figure 6: Temperatures profiles to the solid phase in several kinds of interfacial area.

Theses parameters are crucial in the study of a fluidized bed gasifier since that they are determinants in the reaction and for this reason, in the whole process. Therefore they have been analyzed in this paper.

5. CONCLUSION

The temperature profiles in the solid and gaseous phase gets from the mathematical modeling develop to this reactor showed the forecast of the variables T_g and T_s. This allowed determining the temperatures profiles across of fluidized bed and the behavior of this to some basic parameters of process

Moreover, the developed model allows to analyze the sensibility of the variable Tg (gas temperature) and Ts (solid temperature) with different kinds of porosity and interfacial area. Both parameters present strong influence on Tg and Ts. Therefore, they should be considering in control of FBG (fluidized bed gasifier).

This paper is part of project “**Implementação da Transformada de Fourier para Simulação Computacional dos Processos Fluidodinâmicos, Termodinâmicos e Químicos de um Gaseificador de Leito Fluidizado”** that has aim of building a simulator to a fluidized bed gasifier using biomass as fuel.

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7. NOTACIONS

Tg	gaseous temperature
Ts	solid temperature
$K_{e,p}$	thermal conductivity of the solid phase
$K_{e,g}$	thermal conductivity of the gaseous phase
$C_{p,g}$	gas specify capacity
$C_{p,s}$	solid specify capacity
L	reactor's length
V_g	gas velocity
V_s	solid velocity
h	heat transfer coefficient
a	interfacial area
d_s	particle diameter

8. GREEKS LETTERS

ρ_g	gas density
ρ_s	solid density
μ_g	gas viscosity
ε	bed's porosity

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