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The Influence of Swirl Burner Geometry on the Sugar-Cane Bagasse Injection and Burning

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***Abstract*—**A comprehensive CFD model is developed to represent heterogeneous combustion and two burner designs of supply sugar-cane bagasse into a furnace. The objective of this work is to compare the insertion and burning of a Brazilian south-eastern sugar-cane bagasse using a new swirl burner design against an actual geometry under operation. The new design allows control the particles penetration and scattering inside furnace by adjustment of axial/tangential contributions of air feed without change their mass flow. The model considers turbulence using RNG k-ε, combustion using EDM, radiation heat transfer using DTM with 16 ray directions and bagasse particle tracking represented by Schiller-Naumann model. The obtained results are favorable to use of new design swirl burner because its axial/tangential control promotes more penetration or more scattering than actual design and allows reproduce the actual design operation without change the overall mass flow supply.

***Keywords*—**Comprehensive CFD model, sugar-cane bagasse combustion, swirl burner.

I. Introduction

THE burning of solid fuels in boilers and combustion chambers is strongly influenced by its supply strategy because its combustion is governed by released volatiles burning. Among the ways to insert fuel solids in confined combustion systems there is the use of swirl burners which dragging air has an axial component, to promote penetration of the fuel inside boiler, and a tangential component, to provide higher mixing and spreading of the material with gas flow. This strategy of bagasse supply with swirl burners increases the flame stability, attenuates possible oscillations and unburned material deposits in the boiler surfaces, improves the combustion control and allows the burning of bagasse with high moisture contents [1].

In the present work CFD simulations are used to compare the bagasse burning promoted by two different designs of swirl burners, an actual design already under operation and a new one, not installed yet. The swirl burner is composed by two concentric pipes which the internal pipe is used to flow the bagasse particles and axial air and the external annulus where the tangential air flows under rotation. The axial and tangential mas flow rates and the bagasse particles interact themselves near the exit burner, a fez centimeters from the combustion chamber entrance. In the actual design, the tangential air is driven in the clockwise or anti-clockwise directions by a valve placed before the air enters in the external pipe. In the new, design the rotation direction is imposed by a set of blades installed in the external annulus. This set of directional blades can be displaced to forward and backward that allows regulate the intensity of rotation of air supply in the mixing between solid particles and gas phase. If the blades are set in the backward position, the burner operates under open arrangement and the influence of tangential is reduced because part of the tangential air can flow axially before external annulus exit and be mixed with central pipe flow. If the blades are placed in the forward position, the burner operates under the called closed arrangement and the geometry imposes that all air in the external annulus flows through the directional blades promoting maximum rotation to the tangential air supply. Figs. 1 and 2 present the main characteristics of the burner designs actual and new and the arrangements open and closed to new design burners.

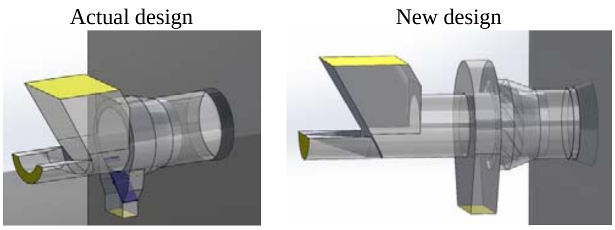

Fig. 1 Actual and new designs to swirl burners to sugar-bag

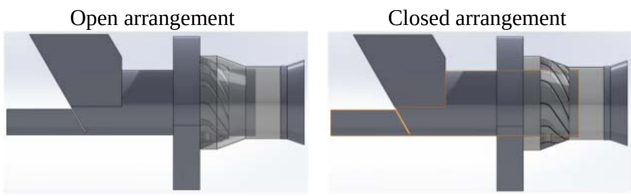

Fig. 2 Open and closed arrangements to new design swirl burner to sugar-bagasse combustion

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II. Methods

To the present work, CFD isothermal simulations were done using RANS turbulence models standard k-ε, RNG k-ε, BSL and SSG in ANSYS CFX 14.5.7. Among these tested models, the RNG k-ε model presented the best results according the expected flue gas behavior downstream burner exit and it model was chosen to represent the turbulent mixing of gas phase flow and bagasse solid particles. The RNG k-ε model was used to represent fluid flow under predominant rotation [2]. The homogeneous combustion inside combustion chamber is represented by the Eddy Dissipation Model (EDM) because the operational conditions inside boiler furnace provides high oxygen and temperature available enough to consider combustion of volatiles be governed by turbulent mixing determined by turbulent time scale, k/ε [3]. To estimate the composition of the volatiles released, it was utilized the proximate and ultimate analysis obtained from University of São Paulo –RibeirãoPreto laboratory and IPT-SP (Institute of Technology Research – São Paulo) to sugar cane bagasse samples from south-eastern Brazil. The chemical mechanism to homogeneous combustion is composed by two reactions:

$$CH_4 + O_2 \rightarrow CO + H_2O \quad (1)$$

$$CO + O_2 \rightarrow CO_2 \quad (2)$$

The CH_4 represents the set of light hydrocarbon species released from bagasse particles in volatilization stage. The radiation heat transfer is represented by Discrete Transfer Method (DTM) that considers the isotropic emission, reflection and spreading of the radiation intensity [4] in 16 directions equally spaced for whole computational domain. Despite the one-way coupling is adequate to represent the momentum exchange between disperse and continuous phases due to low particles concentration in the computational domain, the heat exchange between those phases needs to be represented by two-way coupling. By one hand, all gaseous fuel comes from volatilization and char consumption of bagasse particles combustion stages, by the other hand it is necessary heat flux from gas phase to bagasse particles to activate the process of heterogeneous combustion process. Therefore, there is a two-way exchange of influences between the considered phases. The Schiller-Naumann model can be used to represent the bagasse particles dragging inside boiler furnace. It considers each solid particle as rigid sphere.

III. Simulations

It was done 6 simulations for isothermal air flow without particles (clockwise and anti-clockwise senses for actual design and open and closed arrangement to clockwise and anti-clockwise senses for new burner design), 6 isothermal simulations considering 10,000 bagasse particles and more 6 simulations considering the heterogeneous combustion of 10,000 bagasse particles. In the uniform isothermal simulations, only the influence of the geometry in the air flow was evaluated. In the isothermal simulations considering the disperse phase, the particle dragging also was evaluated without considering the gravitational field. In the heterogeneous combustion simulations, the bagasse burning is evaluated considering gravity and an ascendant uniform air flow rate of 2 kg/s in the far field section of the computational domain, representing the influence of primary air supplied in the bottom grate of the boiler. Fig. 3 shows the computational domain illustrating the main boundary conditions.

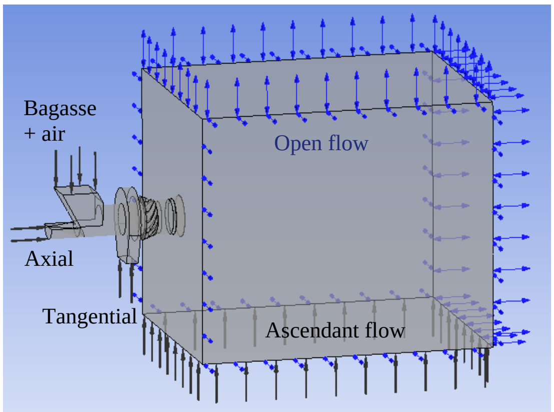

Fig. 3 Computational domain and main boundary conditions considered in the heterogeneous combustion simulations.

Table I presents the boundary conditions used.

TABLE I
BOUNDARY CONDITIONS USED IN THE SWIRL BURNER SIMULATIONS

Domain	Ref. Pressure	1atm		
	Ref. Density	0.66 kg/m^3		
	Turbulence	RNG k-ε		
	Phase coupling	2 way, Schiler-Naumann		
	Gravity	X (m/s^2)	Y (m/s^2)	Z (m/s^2)
		0	-9.81	0
Inlet		Mass flow	Temperature	O_2*
	Axial	0.620 kg/s	25°C	0.232
	Bagasse (air)	0.070 kg/s	60°C	0.232
	particles	*4.130 kg/s*	*60°C*	*0.232*
	Tangential	0.690 kg/s	25°C	0.232
	Ascendent	2.000 kg/s	600°C	0.232
Walls	Temperature	Adiabatic		
Outlet	Opening	Pressure	Temperature	O_2*
		-49 Pa	600°C	0.232

* mass flow

The size diameter distribution of the particles is obtained from [5] and is presented in Table II.

TABLE II
BAGASSE PARTICLE SIZE DISTRIBUTION USED IN THE SIMULATIONS OF THE SWIRL BURNERS

Size, sieve opening (mm)	Mass fraction
5,660	0,0645
2,830	0,0965
1,190	0,1291
0,590	0,3160
0,297	0,2585
0,149	0,1125
0,050	0,0229

Table III presents the proximate and ultimate analyses are based on [6] and Equipalcool Sistemas data.

TABLE III
PROXIMATE AND ULTIMATE ANALYSIS FOR BAGASSE

Proximate analysis		Ultimate analysis	
Material	Mass frac.	Element	Mass frac.
Ash	0.0244	C	0.4759
Moisture	0.0200	H	0.0573
Char	0.1095	O	0.4195
Volatiles	0.8461	N	0.0019
LHV	6.6 MJ/kg	S	0.0006
Reference	25°C, 1 atm	Cl	0.0004

The volatilization rate is represented by Arrhenius equation which parameters from [7]:

$$A = 2{,}13\times10^{6}\ s^{-1} \quad (3)$$

$$E = 92\ 600\ J/mol \quad (4)$$

It is shown results for 6 cases:

Actual design

1. Clockwise direction
2. Anti-clockwise direction

New design

3. Open clockwise direction
4. Open anti-clockwise direction
5. Closed clockwise direction
6. Closed anti-clockwise direction

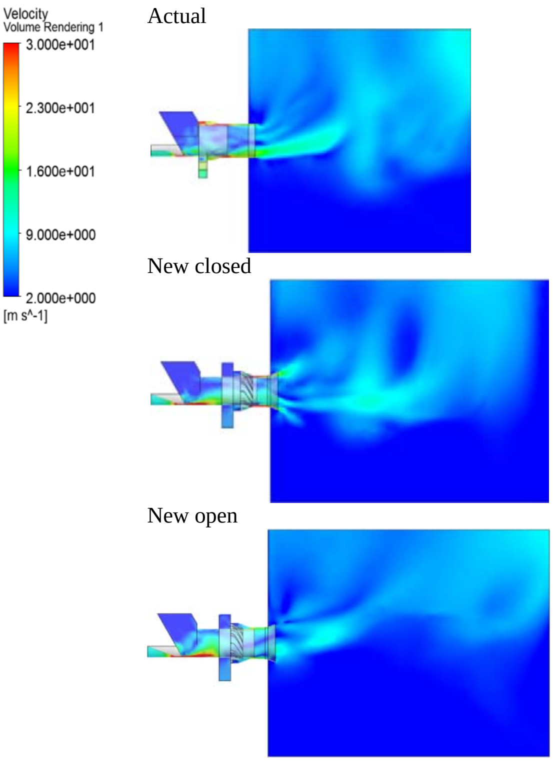

Fig. 4 Vertical velocity profile to bagasse heterogeneous combustion simulations

IV. Results

As expected, the flow behavior obtained in the isothermal cases for all arrangements is the same to the two rotation directions, which evidences that the obtained flow is symmetrical about the rotational direction. So, the next discussions based on anti-clockwise direction results.

The big particles penetrate more inside far field than medium and small ones. The small particles are dragged by ascendant flow near the burner exit. The new design under open arrangement provides the highest penetration among the other cases and the actual burner design presents a softer size distribution along the penetration line in axial direction insider furnace.

It is expected that the velocity profile and particle trajectories influence on bagasse heterogeneous inside far field. Fig. 4 presents the vertical velocity profiles to heterogeneous combustion in the three swirl burners design arrangements.

The new design open arrangement promotes more penetration and the close arrangement more mixing of flue gas flow with particles. The actual burner design shows an intermediate behavior between the two new design geometries. The big particles fall far from burner exit and the medium and small particles suffer more influence from gas flow, promoting small and ash particles ascendant tracking. Fig. 5 presents 90 particle trajectories plotted with char mass fraction, produced after volatilization step.

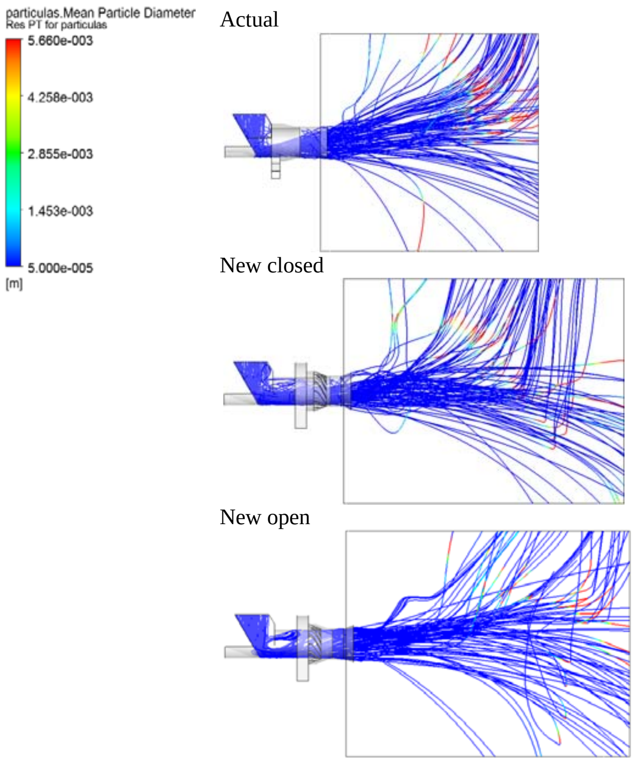

Fig. 5 Char mass fraction in 90 particle trajectories in bagasse heterogeneous combustion simulations

In both burner designs there is a kind of "char production-consumption front", suggesting that is possible to control the bagasse volatilization by geometry changes of the swirl burner geometry. As the heterogeneous combustion is controlled by its volatilization, the burner geometry modifications increase the combustion control and its flame position. This "flame front" is not observed in the new design open arrangement which this char production-consumption line is so far from burner exit that it isn't clear in the lateral view of Fig. 5. Fig. 6 presents volume rendering to temperature on the frontal and lateral views.

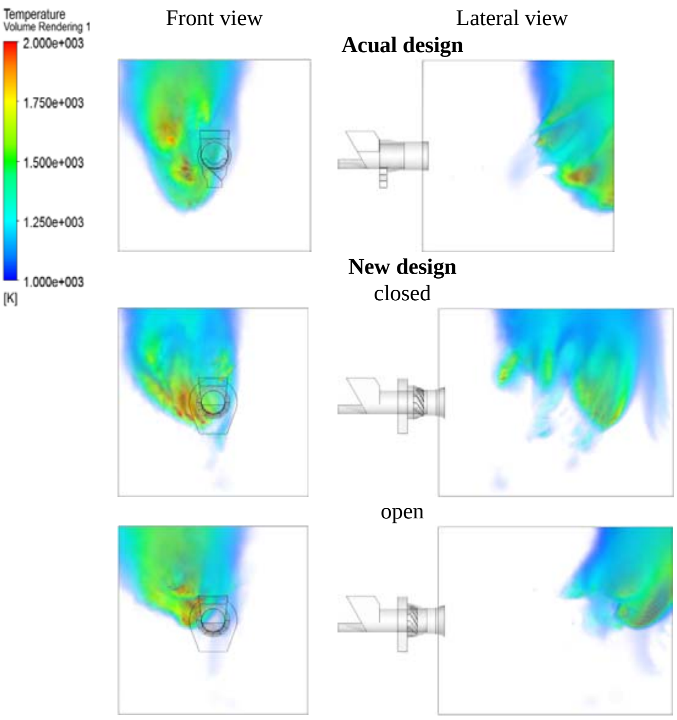

Fig. 6 Temperature volume rendering obtained for all swirl burners simulated geometries

V. Conclusions

The development of a CFD comprehensive model showed itself a useful tool to study and evaluate the project of new concept and design to a sugar-cane swirl burner. Simulations to isothermal homogeneous flow, two-phase particle tracking under isothermal flow and heterogeneous combustion were performed to compare the new design against the actual burner, under operation in Brazil southeaster mills. Even using the EDM that represent the gas phase combustion governed by turbulent time scale, the thermal and chemical species mass fraction profiles show more dependence with volatilization from bagasse particle trajectories than with the flue gas flow. According to results it is possible affirm that the new proposed design provides more control of the bagasse combustion and the operation of the actual design can be reproduced like an intermediary arrangement between the new design open and closed configurations.

Acknowledgment

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References

[1] T. F. Dixon, A. P. Mann, F. Plaza, W. N. Gilfillan, "Development of advanced technology for biomass combustion - CFD as an essential tool". *Fuel*, vol. 84, pp. 1303-1311, 2005.
[2] H. K. Versteeg, W. Malalasekera, *"An introduction to computational fluid dynamics – the finite volume method"*. Second edition. England, Pearson Education Limited, 2007.
[3] S. R. Turns, *"An introduction to combustion: concepts and applications"*. McGraw-Hill, New York, 2000.
[4] Modest, M. F.; *"Radiative Heat Transfer"*. Second Edition. Academic Press, 2003.
[5] Sosa-Arnao, J. H.; *"Caldeiras aquatubulares de bagaço - Estudo do sistema de recuperação de energia"*. PhD. Thesis, UNICAMP, Campinas, SP, Brazil, 2008.
[6] R. Saidur, E. A. Abdelaziz, A. Demirbas, M. S. Hossain, S. Mekhilef, "A review on biomass as a fuel for boilers". *Renewable and Sustainable Energy Reviews*. vol. 15, pp. 2262-2289, 2011.
[7] K. S. Shanmukharadhya, K. G. Sudhakar, "Investigations of effect of bagasse pyrolysis kinects on combustion and boiler performance". *Journal of Energy Institute*. vol 80, issue 1, pp. 40-47, 2007.