Authors:

Machado Jr., Antonio R.
Ferraz, André D.
Lehmkuhl, Willian A.
Azevedo, Jorge G. W.
Rocha, Ivan Carlos C. da
Konishi, Ricardo
Nicolau, Vicente de Paulo
Possamai, Talita Sauter
Nunes, Andréa Trombini

Abstract

In high temperature kilns fuel is an important subject since it may cause high influence in the total costs of products. In these cases issues related to energy efficiency are a permanent quest. Thus some studies were performed with the objective of helping the energy efficiency improvements in high-temperature industrial processes like lead crystal glasses and sodium silicate. By data collection and a validated numerical simulation a thermal balance was developed. In the second step technical actions were commented. Regarding the results, the study showed that up to 80% of kiln inlet energy is lost by chimney, walls and ceiling of kilns. The computational model demonstrated that wall thermal insulation improvements can reduce up to 4% of thermal losses if kiln wall thickness is considerably enlarged. There was no significant temperature increasing in sodium silicate kiln when burner and chimney have moved their position. A low cost heat exchanger was modelled using numerical simulation. This equipment resulted in an estimated efficiency up to 18% for the case of sodium silicate kiln and provided 250ºC heating for air outlet flow.

1. Introduction

Some inorganic industrial processes such as the production of lead crystal glass and sodium silicate require temperatures around 1400° C. Often in such cases natural gas is used for a large amount of energy supplying in specially designed furnaces. In these devices the residence time of flue gas is very short, resulting in heat exchanging efficiency reduction. This implies a direct increasing in the cost of products. These heat losses can strongly contribute to the activity burdening, reducing the viability of some companies. Regarding the characteristics of materials, Shreve and Brink Jr. (1997) commented that lead crystal glass and sodium silicate are defined as a sub cooled liquid with high viscosity and harshness. In the process of production of lead crystal glass is used silica, alkalis and lead oxide, yielding a high refractive index and optical product usually for decorative purposes. In the production of sodium silicate sand is used as silicon source and sodium carbonate as a fluxing agent, resulting in varying composition of silicates each having its specific use. The lead crystal glass furnaces operate in a batch process using a natural gas burner directed to an alumina crucible. In this place raw material melting occurs. In the other hand sodium silicate furnace works in a continuously raw material feeding in the back side of the kiln. At this location there is an impact of the flue gases in the stack of material and when it reaches its melting temperature, product flows by gravity from the front of the oven. Heat exchangers are used for combustion air preheating in the lead crystal kilns, while a single pipe over the sodium silicate kiln is taken to air warming. Figures 1 and 2 show illustrations of kilns used in such processes.

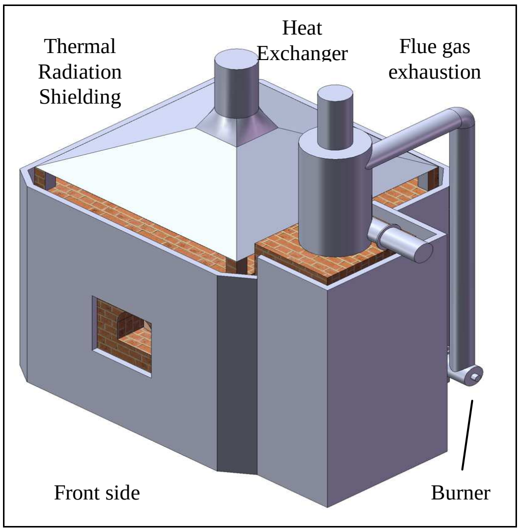

Figure 1 Lead crystal kiln

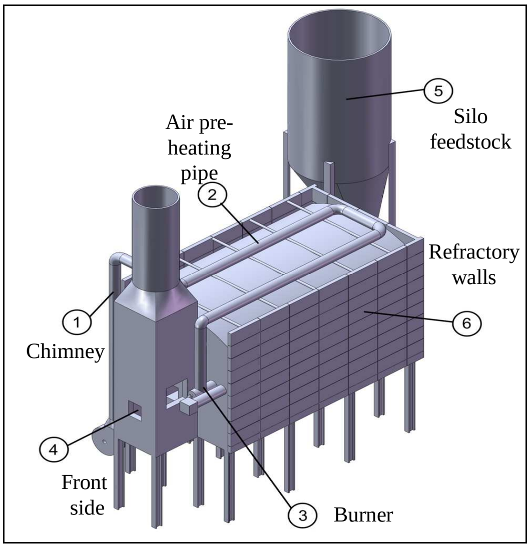

Figure 2 Sodium silicate kiln

2. Methodology

The study was performed in lead crystal glass and sodium silicate producers companies located in Santa Catarina state, Brazil. At initial step some data collection were taken about kiln operating conditions, furnace shape and fluid dynamic flows. On this information numerical simulations were developed through fluid dynamics high-performance (CFD) software. In the second step these computer simulations were validated and technical subjects like: air combustion preheating, thermal insulation, heat exchangers and burners positioning were discussed. Some instruments such as thermocouples, infrared cameras, pyrometers, gas meters, anemometers and Pitot tubes were used in the thermal process assessment. In this step phenomena like conduction, convection and radiation as well as gas flow in the cavities of the kilns were assumed as steady state. The sodium silicate kilns were analyzed in continuously operating mode with material input and extraction. As the lead crystal glass kilns work in batch process they were analyzed considering only the extraction of material and not its replacement. Regarding combustion process, it was based on the chemical species conservation equation solving, considering methane as the predominant component in the natural gas composition.

Equation 1 shows the fundamental combustion reaction used in the study.

$$CH_4 + 2(O_2 + 3{,}76N_2) \rightarrow CO_2 + 2H_2O + 7{,}52N_2 \quad (1)$$

Figures 3 and 4 show respectively pictures of lead crystal glass and sodium silicate production kilns.

Figure 3 Lead crystal glass kiln

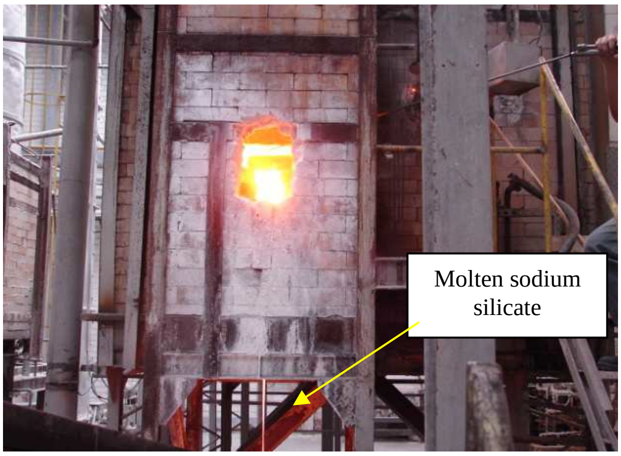

Figure 4 Sodium silicate kiln

3. Results

3.1. Measurements and Calculations

Through the measurements performed it was found that there is air excess in the lead crystal glass kiln up to 97% and 12% for the case of sodium silicate kiln. In both kilns the natural gas combustion was complete. The values for combustion air pre-heating temperatures were about

256°C for lead crystal glass kilns and just 44 ° C for the sodium silicate kilns. This low thermal efficiency is related to a non-effective preheating system, which consists in a metal pipeline passing on the silicate kiln top. With respect to the thermal balance it was found that up to 67% of incoming energy leave the system through furnaces crystal glass chimneys, 17% is taken with products and 13% leave the equipment through the walls and ceiling. For the sodium silicate kilns 62% of the energy is lost through the chimney, 16% are carried with the products and the remaining 10% are lost through the walls and ceiling kilns. Table 1 shows the values of the variables found in different equipment in the course of work.

Table 1. Processes parameters measurements

	Kiln	
	Lead crystal glasses	Sodium silicate
Incoming thermal energy (kW)	204	1275
Working temperature (ºC)	1.235	1.200
Air combustion temperature (ºC)	256	44
Air excess (%)	97	12
Chimney thermal loses (%)	67	62
Product thermal loses (%)	17	16
Walls and ceiling thermal loses (%)	13	10
Other loses (%)	3	12

A 50% reduction in ceiling and walls loses was observed in lead crystal glasses kilns with radiation shield.

3.2. Numerical Simulation Model Development

After collection data and calculations proceedings a numerical model and its validation were conducted. The results showed a significant correlation when compared to acquired data. Figures 5 and 6 respectively represent measured and simulated thermal losses values for lead crystal glass and sodium silicate kilns.

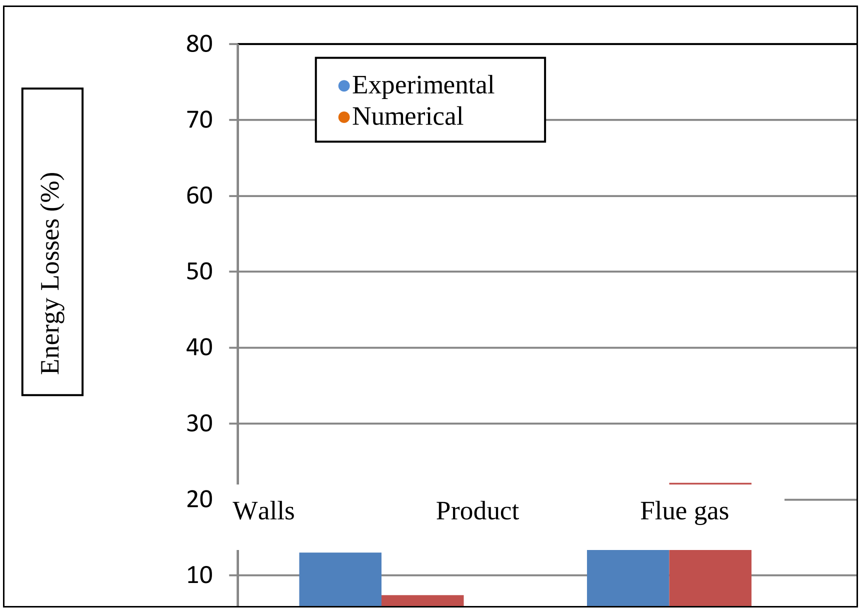

Figure 5 Experimental and numerical comparison lead crystal kilns data

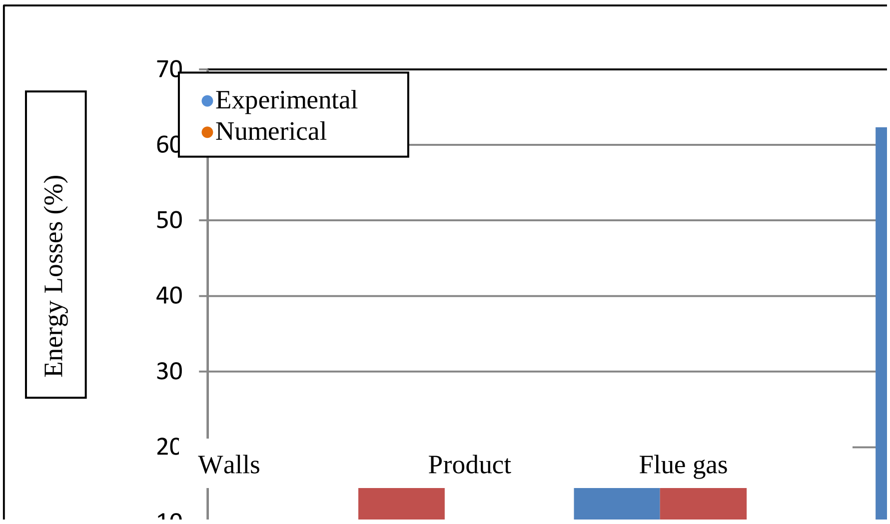

Figure 6 Experimental and numerical comparison sodium silicate kilns data

3.3. Working Simulation

3.3.2 Additional Wall Insulation Simulation

In order to reduce walls thermal losses a numerical simulation was done virtually increasing insulation layer of sodium silicate kilns. Three cases were studied: a) Insulation 1: Increasing wall insulation twice; b) Insulation 2: increasing four times the insulating layer; c) Isolation 3: increasing eight times the insulating layer. Figure 7 shows comparison between standard conditions (actual insulation) and virtually simulated cases. The terms "Walls losses", "Load transferred charge" and "Flue gas transferred energy" correspond to the energy lost through the walls, absorbed by the load and carried by flue gas respectively.

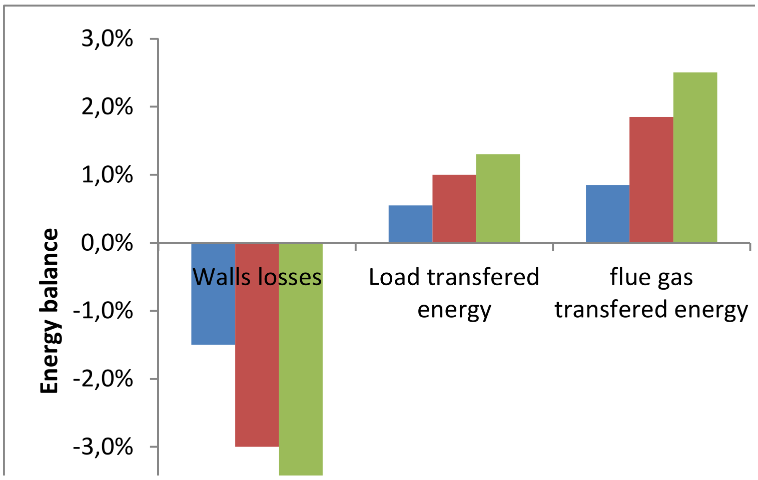

Figure 7 Energetic balance compared to thermal insulation simulated cases

The simulation results showed that up to 4% of walls energy losses can be prevented when compared to standard insulation conditions. This energy is redirected trough the kiln being 35% absorbed by the load while the remaining heat goes out the chimney.

3.3.3 Burner Positioning Simulation

A simulation about sodium silicate kiln burner positioning was performed considering the following situations: a) case 1 - standard conditions α = 0º; b) case 2, α = 30º and c) case 3, α = 45º. Figure 8 represents the different positions in burner position.

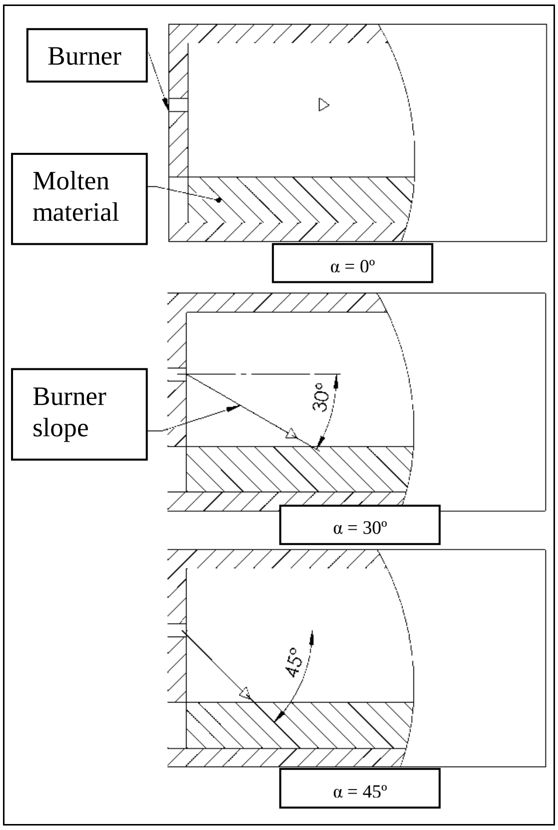

Figure 8 Different positions burner

According to the Figure 9 there was not considerably temperature increasing in the load surface.

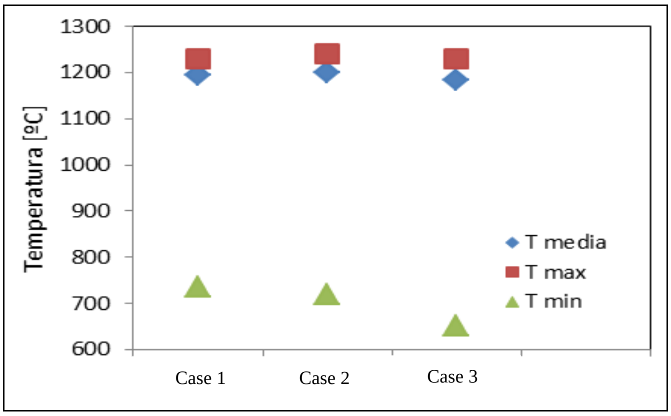

Figure 9 Load temperature achieved

Figure 10 presents thermal images resulting from burner positioning simulations and their respective temperature achieved.

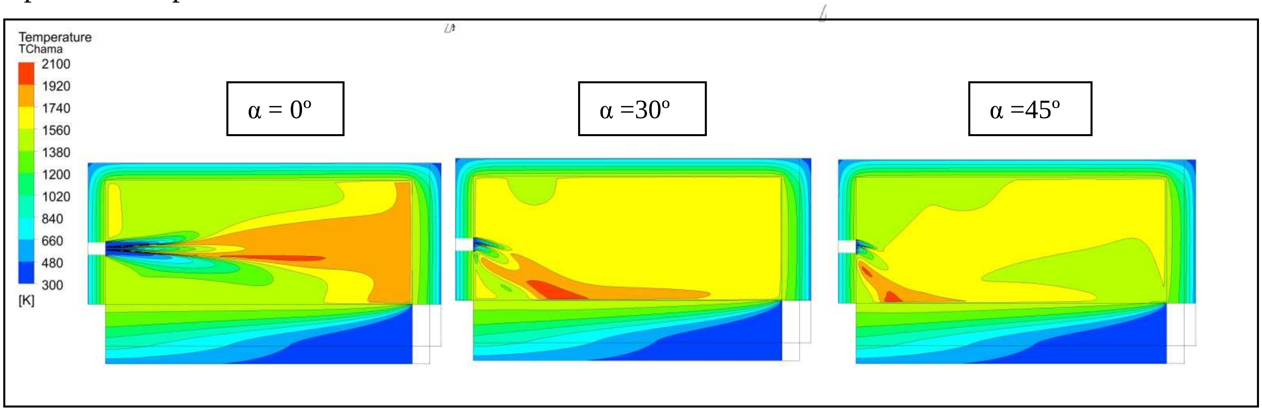

Figure 10 Sodium silicate thermal images

3.3.4 Burner and Chimney Positioning Simulation

Burner and chimney positioning are related to flue gas residence time and have influence on energetic exchanging. Two positioning exchanging were analyzed in sodium silicate kilns as the following examples: a) moving the chimney to kiln center; b) putting burner and chimney in opposite sides. Figure 11 presents both cases compared to standard positioning.

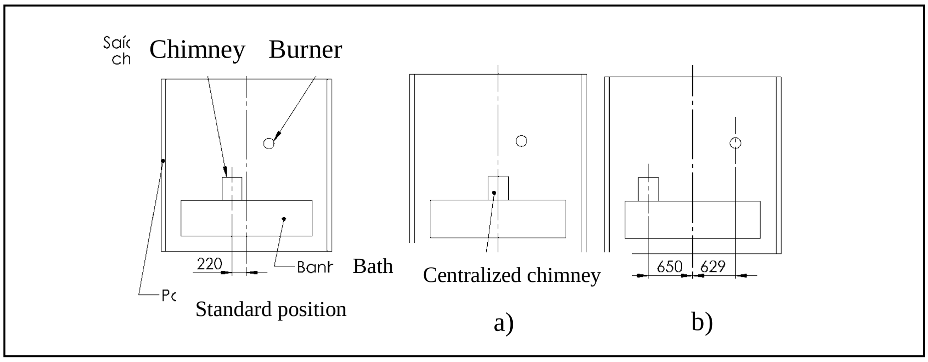

Figure 11 Sodium silicate burner and chimney positioning

There was no significance in the burner and chimney positioning exchanging results since the energetic gain was less than 1%.

3.3.4 Heat Exchanger Configuration Simulation

In order to achieve a better energy recovering a low cost heat exchanger model was virtually developed by computational means. A configuration based on several tubes arranged transversely to the flue gas was adopted as Figures 12 and 13 present.

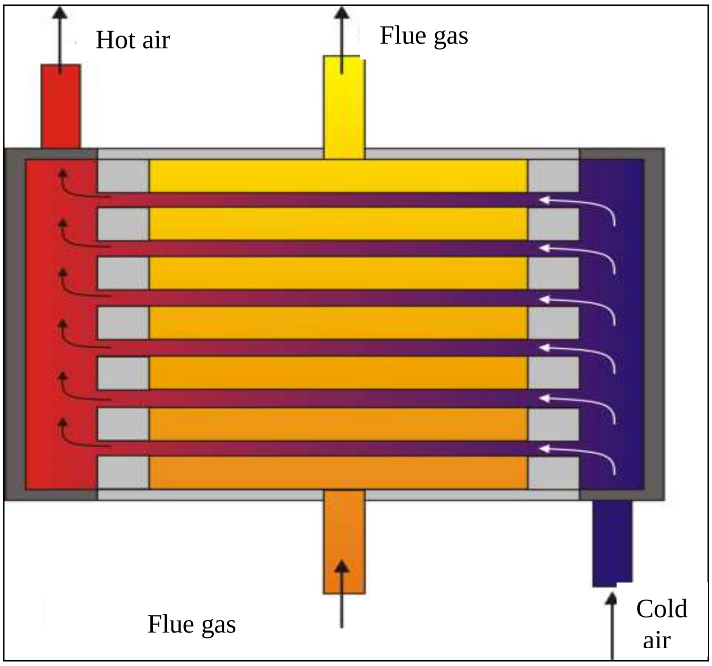

Figure 12 Heat exchanger lateral view

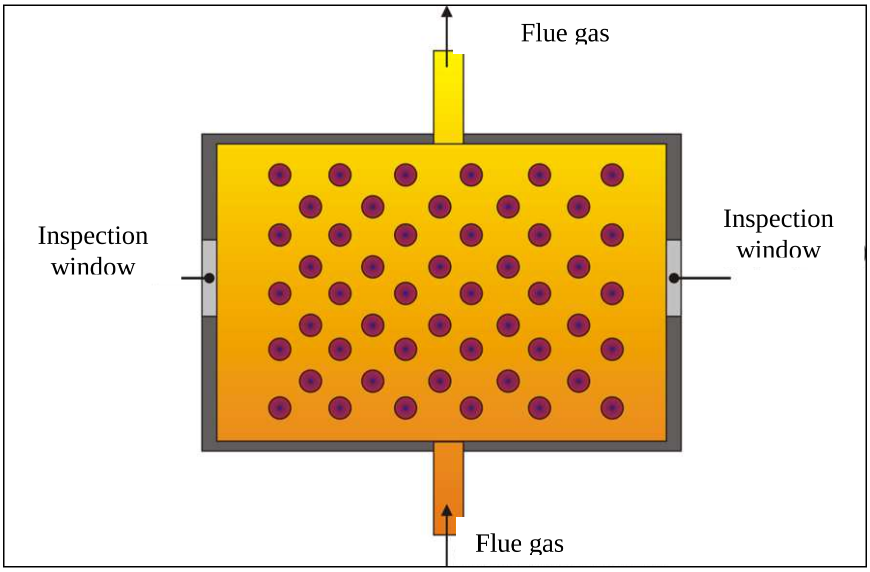

Figure13 Heat exchanger front view

The figures above show a 2m (high) and 1,2m (width) heat exchanger configuration numerically modeled able to be used attached in kiln chimney. Preliminary tests using 210 pipes presented an increase of approximately 18% in energy efficiency. Table 2 brings analyzed parameters in the numerical modeling.

Table 2 Characteristics of numerically modeled heat exchanger

Parameters	Characteristic/value
Pipe material	Alumina
N.º pipes	210
Estimated efficiency	18 %
Flue gas temperature inlet	1200 ºC
Flue gas temperature outlet	1000ºC
Air temperature inlet	25 ºC
Air temperature outlet	250 ºC
Walls thermal losses	15 %

This kind of heat exchanger could be used in sodium silicate kiln providing combustion air temperature variation from 44ºC to 250ºC. This could result in 8% reduction in natural gas consumption considering that for each 25ºC increasing corresponds to 1% of energy economy.

3. Conclusions

The experimental data collected has quantified the thermal losses in high-temperature kilns through energy balance. It was found that most of the consumed energy in the furnace is lost by the flue gas, representing up to 67% of the energy entering the system. Much of these energy losses are related to geometric characteristics of kilns and air excess used, which measurements reached 97%. Through the walls and ceiling 13% of energy is lost. However, this value can be 50% higher if the heat shields plates are not used. Simulations results showed that if the insulating walls thickness is increased by 8 times there will be a possibility of 4% reduction in energy losses. Not being economically justified, at first, any change. Moreover, this recovered energy will tend to increase the kiln temperature, causing greater wear on the refractory tiles. No significant gains were seen with respect to the positioning exchanging of burners and chimneys. A low cost heat exchanger was simulated using alumina pipes in a transversal arrange achieving thermal efficiencies about 18%. This could provide an 8% reduction in natural gas consumption for sodium silicate kiln. Overall the study showed that numerical simulations method was consistence with the measurements done. This fact contributed to the prediction of the kilns behavior with no downtime or architectural changing. As result a better knowledge in decision making about energy efficiency improvements was acquired.

4. Acknowledgements

Executive Producer: Prof. Vicente de Paulo Nicolau, Dr. – Coordinator - vicente@lmpt.ufsc.br; Eng. Talita Sauter Possamai, Dr. – Researcher - talita@labcet.ufsc.br; Eng. Renato Oba, M.Sc. – Researcher – renatooba@labcet.ufsc.br and Eng. Andréa Trombini Nunes , M.Sc.

Universidade Federal de Santa Catarina – UFSC. Florianópolis - SC.

5. References

SHREVE, R. Norris; BRINCK JUNIOR, Joseph A.. **Indústrias de Processos Químicos.** 4. ed. Rio de Janeiro: Guanabara Koogan S.a., 1997. 717 p. Tradução: Horácio Macedo.