Authors

Azevedo, Jorge G. W.
Ferraz, André D.
Lehmkuhl, Willian A.
Machado Jr., Antonio R.
Rocha, Ivan Carlos C. da
Konishi, Ricardo
Francisco Jr., Roberto W.
Oliveira, Amir A. M.

Abstract

Traditional thermoforming processes are based on electric radiant panels. The plastic sheet passes between them to be heated to pliable forming temperature and then is stretched onto a mould to a specific form. This paper describes the development and operational costs savings of a natural gas pre-heater device that can be coupled to an electric thermoforming machine. Using natural gas to pre-heat the plastic sheet before the thermoforming in the electric machine can reduce costs in the process. The prototype built was conceived to replace part of the electrical energy and consists in one panel under the plastic sheet, with 24 radiant porous burners, eight lines with three burners each. The pre-heater can heat the plastic sheet up to 120ºC and the final heating, from 120º to 160ºC, is done by the electric thermoforming machine. The combustion system had a capacity range from 48 kW to 96 kW and was developed to keep the air-fuel equivalence ratio constant. The project was developed having the operator safety in mind and sensors can detect if the machine stops so the panel slides horizontally to avoid burning the plastic sheet. Flow meters were installed to gauge natural gas and air flow rates. The prototype was tested in a production environment, producing disposable plastic cups from 0.55 mm polypropylene sheets. It produced the plastic cups successfully within the quality parameters. Considering only the heating phase it brought 20% reduction in costs and 40% reduction in electric energy consumption.

1. Introduction

Ninety five percent of the natural gas industrial market in the Brazilian Santa Catarina state is comprised of the following sectors: ceramics, metal-mechanics, textiles and glass. The Santa Catarina Gas Company has set a strategy to diversify this market by investing in research and development in new areas like replacing electric heating. Conventionally, plastic cups are produced by electric thermoforming machines. A plastic sheet is heated, by electric radiant panels, generally one above and one underneath, to bendable temperature and then is stretched onto a mould. This process is broadly used in the Santa Catarina State, one of the largest plastic cups producers in Brazil. This process is also used in other appliances pieces manufacture.

There are some challenges to make a whole thermoforming plastic machine. Electrical resistance heaters allow finer temperature adjustments that are required in the moulding process and hence, this project proposes a pre-heating stage with natural gas. Conversely, using natural gas brings some benefit because electrical resistances have short lifespans and need to be replaced regularly.

The aim of this Project was to develop technology to allow the use of natural gas in the manufacture of disposable plastic cups. The prototype was conceived as a modular pre-heater before the usual electric machine. This design provided flexibility in which it would allow a current electric thermoforming machine to use natural gas to pre-heat the plastic sheet or use electric energy solely in the process. The natural gas burners were radiant porous ceramic burners. These burners achieve high flame temperatures, high range of power and low emissions.

2. Methodology

The development of the prototype was divided in three main parts:

1) The combustion system containing the fan, control panel and flow meter;

2) The radiant panel containing 8 burner rows, the ignition and flame detection system, the solenoid valves and the gas manifold for the reactants distribution;

3) The structure of the pre-heater, containing the drive system for the radiant panel, the drive system for plastic sheet and the cowling.

The whole concept was designed by the Laboratory of Combustion and Engineering of Thermal Systems (LabCET) at the Mechanical Engineering Department, Federal University of Santa Catarina (Figure 1). The combustion system was built by a third party. The radiant panel with 8 rows with 3 burners was assembled by the LabCET team. The structure of the pre-heater was mounted by an electric thermoforming machine manufacturer, in Criciúma city, where the prototype would later be tested operating in line with an electric thermoforming machine.

Initial tests of the radiant panel and the combustion system were performed at the LabCET. The system was tested for ignition and flame detection. In addition, they also checked the flame stability at the start and during operation at various powers outputs.

Then, the radiant panel and the combustion system were transported to the equipment manufacturer to be coupled to the structure of the pre-heater and thus allowing the testing in line with an existing thermoforming machine in the company.

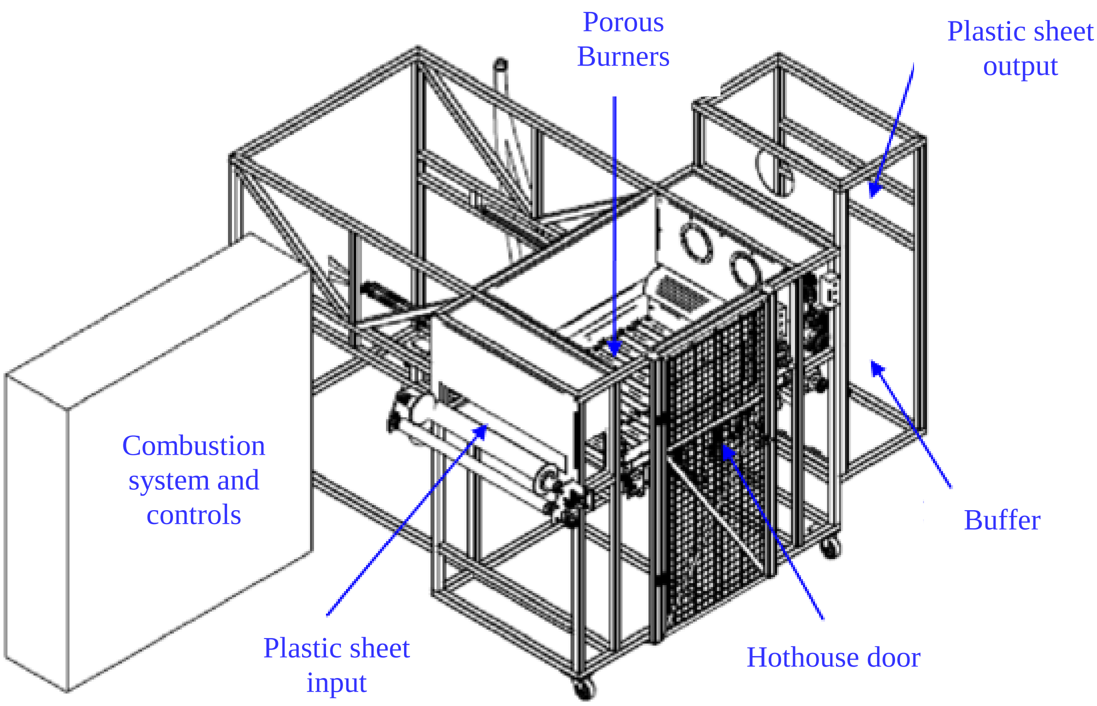

Figure 1 – Concept of the natural gas pre-heater of a plastic thermoforming machine

3. Equipment building

3.1. Combustion System

The combustion system was built in Joinville city and transported to the LabCET to be tested with the radiant panel. Figure 2 shows a picture of the combustion system mounted with the fan, flowmeters, solenoid valves, control panel and other security and control accessories.

The combustion system of the pre-heater includes in the air line a fan, a butterfly valve with servo motor to control the flow of air, a flowmeter for measuring the flow, a manometer and a low pressure switch. In the gas line the system includes a filter, a safety shut-off valve, a pressure regulator that reduces the pressure from 1.5 bar to 60 mbar, a relief valve, a normally closed solenoid valve, a bubble tester, two manometers, a low pressure switch, a high pressure switch, a flowmeter for flow measurement and an injector (venturi valve) responsible for maintaining the equivalence ratio constant and a homogeneous gas mixture.

The mixture of air and gas from the combustion system reaches the burner manifold through a flexible hose that allows movement of the burner panel at times of machine downtime.

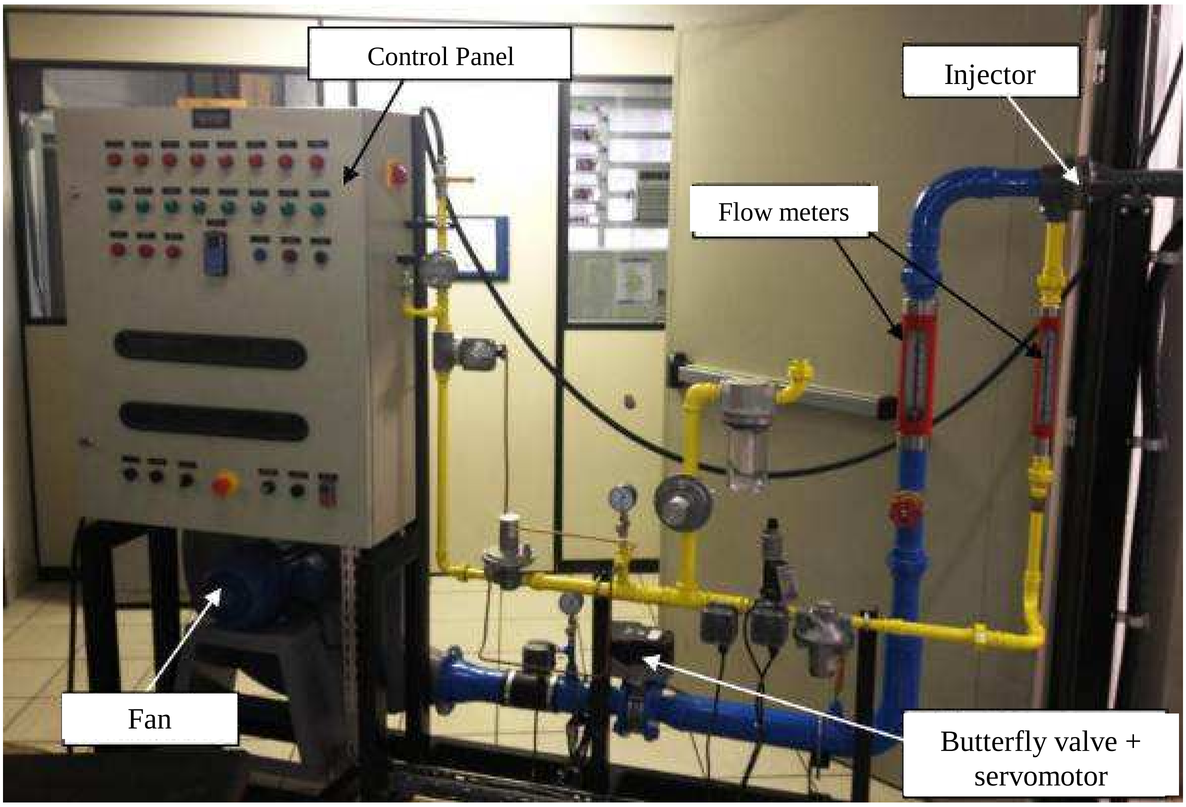

Figure 2 – Combustion system and the natural gas pre-heater controls.

The control panel has the following operating logic. Fan turned on; Butterfly valve opened to 90º; After a pre-set time and checking the low air, low gas and high gas pressure switches the burners are turned on; After confirming the burners are turned on and after a pre-set time the butterfly valve is set to 0º and start to be modulated by the controller according to the setting in the servomotor (range from 0º to 70º).

There is a key to change between manual and automatic modes. In manual mode there are three pre-set opening options for the butterfly valve. In automatic mode the valve is modulated according to the temperature set-point. There is also a button to test the panel lamps to facilitate the detection of burnt signaller lamps on the panel door. The kill switch is a red mushroom pushbutton to stop the system in case of emergencies.

3.2. Radiant Panel

Figure 3 shows the radiant panel. Each row of the radiant panel has on one extremity an igniter and on the other extremity a flame detector coupled to a pilot flame. Solenoid valves in each row allow the shutting off of some rows and thus reducing the radiant area, also reducing energy radiation transferred to plastic sheet.

Moreover, in case of flashback the system closes the valve and blocks the gas passage. In addition to the solenoid valves, each row has a ball valve for manual closing and a valve for fine adjustment of the flow.

Figure 3 – Radiant panel with 8 burner rows.

3.3. Structure of the pre-heater

The final part was the building of the pre-heater structure, which was done by a manufacture of electric plastic thermoforming machines.

4. Tests of operation

The initial tests of the gas pre-heater were done with the radiant panel and the combustion system at LabCET. In this step, the logic of the control system, the stability of the flame, the ignition and detection of the flame, the air flow obtained with the industrial fan, among other parameters were evaluated.

4.1. Logic of the control system

The logic of the control system presented earlier was adequate to operate the radiant panel. The only alteration made to the original design was to include timer relays to keep the solenoid valves of each row open for another ten seconds after closing the main valve in the gas line. This change ensured that the air from the fan continued flowing to the burners after shutting off the gas, preventing flashback.

4.2. Ignition of the burners

The ignition process of the burners should last up to ten seconds. The count starts with the opening of the gas valve and the spark simultaneously. A flame is formed on the surface of the porous medium and propagates to the other modules until it reaches the other end of the firing line, where it ignites the pilot flame to the flame detection.

The parameters that influence the ignition of burners are the power and equivalence ratio. After adjusting these parameters it was possible to obtain a satisfactory ignition of the burners. Figure 4 shows an image of the three lines of ignition firing.

Figure 4 – Burners ignition.

4.3. Flame detection

The flame detection is performed with a pilot and an ionization electrode. The chemical reaction of combustion forms ions that allow the passage of an electric micro-current which is detected in the control panel.

During the tests it was observed that the current detected by the electrode position is very sensitive to the flame. This complicates the flame detection during power modulation of the burners, causing ionization signal loss and closing the gas at times.

There still need to make some adjustments on the flame detection to obtain the expected performance.

4.3. Burners in operation

After ignition, the flame from the burners takes about 1 minute to enter the porous medium and make the ceramic glow. Then, the power of the burners may be reduced to the desired operating point. Figure 5 shows an image of four lines firing in operation.

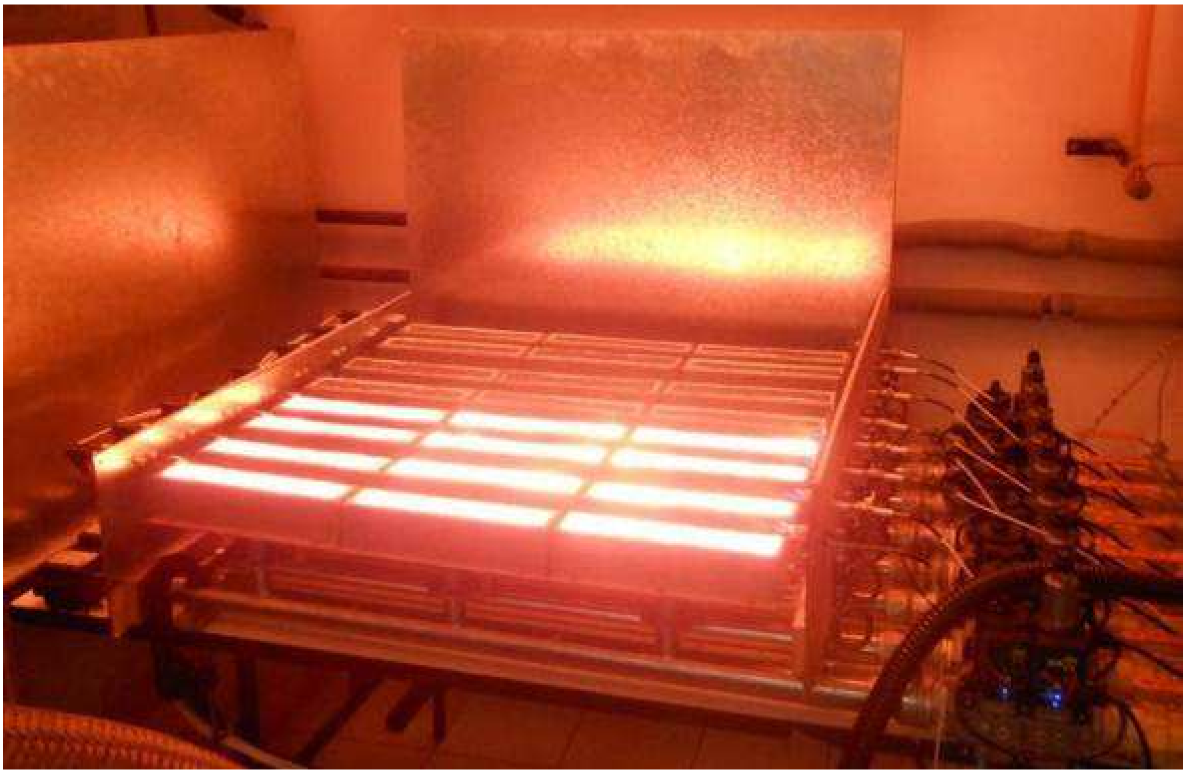

Figure 5 – Burners in operation.

5. Prototype test

The pre-heater prototype was assembled in the thermoforming machine manufacture. There it was coupled to an electric thermoforming machine and then tested in a production environment to produce plastic cups.

Figure 6 – Natural gas thermoforming machine prototype

Figure 6 shows the prototype built, the 0.55 mm polypropylene film roll, the pre-heater hothouse in the middle and the buffer inside the blue door. The buffer is required because the pre-heating is continuous and the electric thermoforming is done in batches. The plastic film pre-heating by the natural gas burners can be seen in Figure 7.

Figure 7 – Plastic film being heated by gas radiant burners


Figure 8 – Plastic cups being produced

6. Conclusion

This study presented the development of a natural gas thermoforming pre-heater machine. It produced plastic cups successfully within the quality parameters. During the prototype test the pre-heater heated the plastic sheet up to 120ºC whilst the final heating, from 120º to 160ºC, was done by the electric thermoforming machine.

Considering only the heating part of the thermoforming machine, adding a natural gas pre-heater brought 20% reduction in costs and 40% reduction in electric energy consumption, which signifies a payback of four years.

7. Bibliographic references

BLASS, Arno. Processamento de Polímeros. Florianópolis: Editora da UFSC. 1985.

CATAPAN R. C., OLIVEIRA A. M., COSTA M. Non-uniform velocity profile mechanism for flame stabilization in a porous radiant burner. 2010

CATAPAN, R. C., PEREIRA, F. M., OLIVEIRA, A. M. Substituição de aquecedores elétricos por queimadores porosos radiantes. 2004.

DILLON, Jeremy. Combustion in Porous Media. 1999.

GLASSMAN, Irvin. Combustion. San Diego: Academic Press. 1987.

MACHADO, G. B., MELO, T. C., LASTRES, L. F. Utilização de Gás Natural em Motores e Cenário do Uso no Brasil. 2007.

MORAES, Rose. Termoformagem. Texto Reproduzido da Revista Plástico Moderno. Edição nº421 - Novembro de 2009

MUJEEBU M. A., ABDULLAH M. Z., BAKAR M. Z., MOHAMAD A. A., MUHAD R. M.,

ABDULLAH M. K. Combustion in porous media and its applications – A comprehensive survey. 2008

PACHECO, Giovanna Lamastra. A Indústria de Gás Natural no Brasil: Sua Importância e a Diversidade na Matriz Energética Nacional. 2008.

PEREIRA, Fernando Marcelo. Medição de Características Térmicas e Estudo do Mecanismo de Estabilização de Chama em Queimadores Porosos Radiantes. 2002.

DURAN, M. A., GROSSMAN, I. E. An outer approximation algorithm for a class of mixed-integer nonlinear programs. *Math. Prog.*, v. 36, n. 3, p. 307-327, 1986a.

DURAN, M. A., GROSSMAN, I. E. A mixed-integer nonlinear programming algorithm for process systems synthesis. *AIChE J.*, v. 32, n. 4, p. 592-606, 1986b.

MAH, R. S. H. *Chemical processes structures and information flows*, Butterworth Publishers, 1990.

MOORE, R. G., BISHNOI, P. R., DONELLY, J. K. Rigorous design of high pressure natural gas pipelines using BWR equation of state. *Can. J. Chem. Eng.*, v. 58, n. 1, p. 103-112, 1980.

MURPHY, L. J., DANDY, G. C., SIMPSON, A. R. Optimum design and operation of pumped water distribution Systems. In: *Conference on Hydraulics in Civil Engineering*, Brisbane, Australia : Institution of Engineers, fev., 1994.

OSIADACZ, A. J., CHACZYKOWSKI, M. Comparison of isothermal and non-isothermal pipeline gas flow models, *Chem. Eng. J.*, v. 81, n. 1, p. 41-51, 2001.

OUYANG, L., AZIZ, K. Steady-state gas flow in pipes. *J. Pet. Sci. Eng.*, v. 14, n. 2, p. 137-158, 1996.