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# SUBSTITUTION OF ELETRICITY BY NATURAL GAS IN TEXTILE STAMPING MACHINES: A NEW TECHNOLOGY

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# ABSTRACT

The textile enterprises' method for stamping textiles is recognized due to its intense electric energy use. The company's monthly electric consumption is generally around 450MWh, from which 30% is destined to the process of drying paints. The drying consists in a series of electric heaters made from halogen bulbs, or electrical resistances, intercalated with the applications of paint. This research intends to discover both technically and economically viable solutions for the system energetic conversion to natural gas. In order to do so, a detailed study of the current procedures was conducted, which enabled a comparative analysis between the current operational processes and the solutions suggested by the research team. Initially, by analyzing the power consumption of the plant as a whole, the amount destined for the drying process was identified. Then, the heat exchange rates through radiation, as well as convection, were analyzed. With these data at hand, the researchers were able to calculate the necessary potency demanded by the new proposed heating settings to supply, with greater efficiency, equivalent performance levels. The substitution of halogen bulbs with radiant tubes heated by natural gas combustion gases, as well as the manufacture of a heater with radiant burners, substantiate the solutions suggested by this paper. Among the many possible answers examined, two successfully distinguished themselves: Radiant Ceramic Tubes Heater, which resulted in an operational costs reduction around 42%, and Porous Radiant Burners Heater, which resulted in an operational costs reduction around 54%.

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## Paper

# 1. INTRODUCTION

SCGÁS's mission consists on providing energetic solutions for the distribution and utilization of natural gas with efficiency, security, reliability and affordability for the sustainable development of the State of Santa Catarina. Within the scope of actions developed by the company, it has been to identify the opportunity of conversion to natural gas from the paint drying stage of the stamping textiles process. The representativeness that the textile sector holds within the Santa Catarina industry is one of the factors that motivated the development of this paper. Thus, through partnership with specialized consulting companies and a textile enterprise, SCGAS developed this study to propose both technical and economical solution for the affordable diversification of the energy matrix through natural gas in the textile segment.

The case analyzed was the stamping textile process in a SCGÁS's client, a textile company, characterized by the intensive use of electric energy. The stamping machines consist of a series of portable electric heaters interspersed with paint applicators. The heaters are constituted by halogen bulbs or electric resistances and have the function of pre-dry the newly applied paint in order to facilitate the successive layers of different colors implementation to form the product stamp without causing any blots. Subsequently, the texture passes through the final drying inside a continuous natural gas oven.

The utilization of natural gas in this process is considered a challenge due to the necessity of applying successive layers interspersed with the paint application. The lack of regularity during the operation is an additional complication, since the texture feeding process is hand-made. There is no commercial solution available in the market that allows the use of natural gas as energy input in such equipments.

Finally, this paper analyzes and suggests some proposals for technical solutions, based on the current operation of stamping machinery and in the preliminary study of technical and economic feasibility of electricity substitution for natural gas in the textiles stamping process.

# 2. TECHNICAL EVALUATION OF CURRENT CONDITIONS

### 2.1 Technical visits

The Project team undertook several visits to the manufacturing plant of a textile company, in order to perform measures within in the current process operational conditions. The visits were accompanied by technical of the electromechanical maintenance sector and works within the company.

The stamping textile process consists in the application of paint, followed by a pre-drying that allows printing of a new color, without causing blots. This process occurs alternatively until the required number of colors is obtained. Figure 1 illustrates a stamping machine model. It is possible to observe in detail the possibility of intercalate the drying steps with paint applications.


Figure 1: On the top, the stamping machine. On the bottom, detail of the drying stage intercalate with the paint application

Currently the pre-drying process is done by two types of segment. The most widely used one consists of halogen bulbs heater that irradiates light and heat controlled space of time. Additionally, an air flowage is made over the lamps with ventilators positioned on the bottom part of the dryers (figure 2).

This heating system has a low thermal inertia and can be turned on/off every drying cycle; thus, provides a greater economy and efficiency to the process.

The dryer is positioned fixedly over the textile to be dried, which is on a sustentation board made of structured aluminum. Even the radiation acting as predominant factor in this drying method, the use of ventilators revealed to be important, because the air flow transports the moisture away from the textile and decreases the cooling time of the lamps and the sustentation boards.

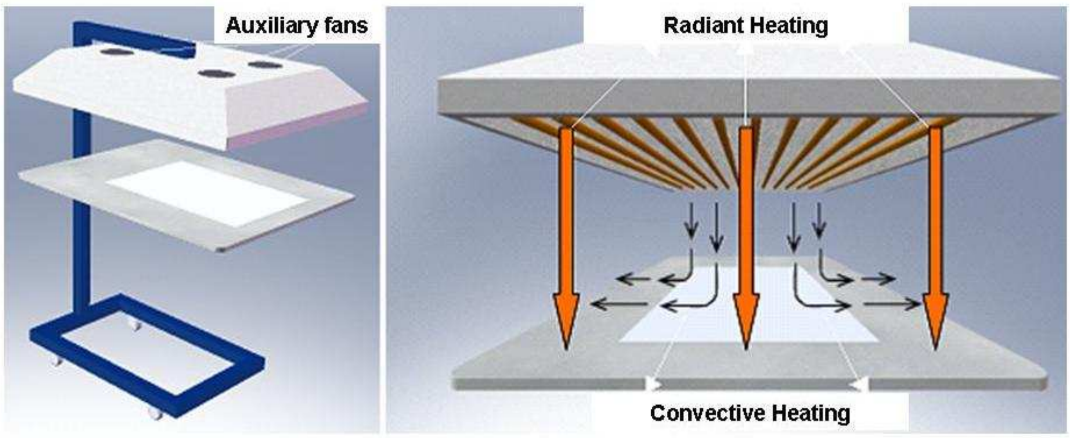


Figure 2: On the left, the drawing of the halogen lamps dryer. On the right, lower view of the dryer with the lamps and the sustentation board in detail

The second model consists of a dryer made of electrical resistors. It works constantly turned on due to the high thermal inertia of the resistive elements, which do not allow the system switching on/off at time intervals sufficiently short, such as those required by the drying cycles. To avoid thermal damage to the textile and the sustentation boards, the dryer is taken out of contact with the board and textile through a pneumatic system at each cycle. This dryer does not operate with ventilators and utilizes only the heat transfer by radiation.

The company offers three models of halogen bulbs dryers and one model of electrical resistors dryer. Table 1 shows the characteristics of each of them, as well as the dryer's amount current in operation and the amount of dryers that the company has been installing for enlarging its manufacturing plant. During the year of 2009, this textile company presented a production regime of two shifts, eight hours per shift, five days a week. In addition to the increase of the equipments amount, the company's expectation is to enhance the production regime to three shifts, which will generate a significant proportional enlargement of the electrical energy consumption in this company sector.

| Dryer type | Total power (kW) | Bulbs per device | Dryers in operation | Dryers in installation |
|---|---|---|---|---|
| Halogen bulb | 10,8 | 9 | 40 | 25 |
| Halogen bulb | 14,0 | 12 | 15 | 8 |
| Halogen bulb | 18,0 | 12 | 30 | 3 |
| Electrical resistance | 4,5 | * | 11 | 0 |
| * The electrical resistances in this dryer model are in the form of continuous wire | | | | |

Table 1: Characteristic of the dryers

Figure 3 illustrates the behavior of heating a halogen bulb with the machine in continuous operation without any load. The observed oscillations are due to the programming of the machine that imposes a brief shutdown of the panel during the cycle. The 400s reached temperature plateau corresponds to the permanent temperature of halogen bulb. This result will be used to calibrate the radiation model to be developed.

Due to the characteristics of the current established production process, the dryer works intermittently. Figure 3 shows an experiment done with the panel to simulate the on/off switching with a 10 minutes cycle, approximately. Thus, it is noticeable that in the studied process, the load that is been heated suffers the influence of an intermittent radiation field. Such aspect should be considered in the proposal of a new system, based on natural gas.

Figure 4 shows a graphic in permanent regime of the dryer bottom. It is able to notice that its permanent regime temperature is around 90ºC. Since the bottom has a much higher thermal inertia than the lamp, its heating period is as well much longer.

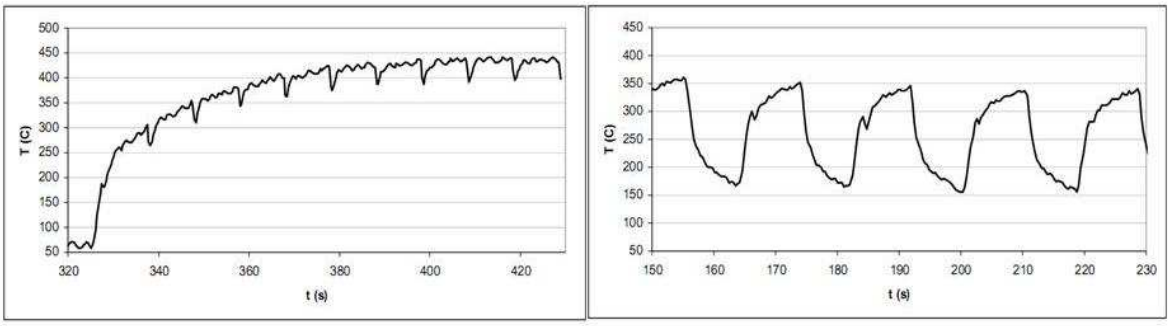


Figure 3: Heating of the halogen bulbs dryer & intermittent behavior of the halogen bulbs dryer

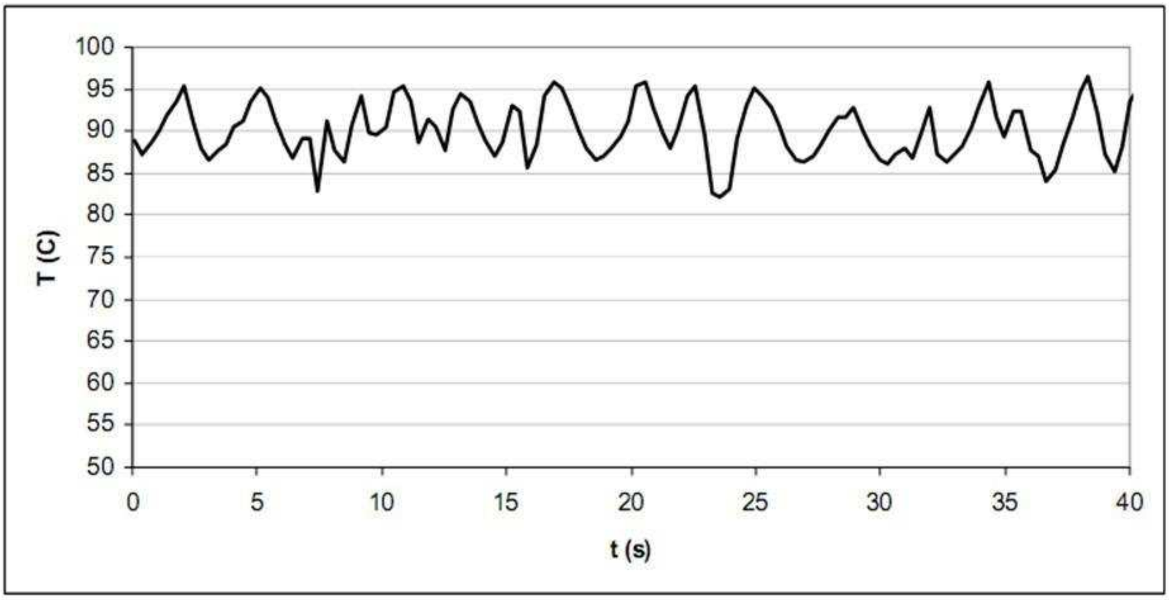


Figure 4: Heating of the bottom dryer

Also, there have been done measurements in the electrical resistances heaters. These operate only in permanent regime with an average operating temperature of 400ºC. Finally, each halogen bulb dryer has ventilators that blow air over the textile. The air flowage must be considered and, therefore, it was measured: average of $5{,}8x10^{-2}$ m³/s per ventilator.

**2.2. Preliminary balance of energy**

The effective average consumption of electrical energy in the analyzed company in 2008 and 2009, according to the invoice issued by the local concessionaire, disregarding the months without any data as well as the months with atypical consumptions level, resulting in 458,7 MWh ($E_{total}$).

Out of this total, it is interesting to know the relative percentage (η, Equation 1) of the electric heating consumption of the stamping section ($E_{heaters}$, Equation 2). In order to do so, it is indicated to know the nominal power installed in the heaters ($P_{total}$, Equation 3), multiplied by effective time of production ($t_{operation}$, Equation 4). The nominal potency installed is calculated by the product sum of the nominal potency of each type of heater ($P_i$) and the respectively amount of installed heaters ($N_i$).

$$\eta = \frac{E_{heaters}}{E_{total}} * 100\% \tag{1}$$

$$E_{heaters} = t_{operation} * P_{total} \tag{2}$$

$$P_{total} = \sum_{i=1}^{n} N_i * P_i \tag{3}$$

$$t_{operation} = t_{totalmonthly} * \left(\frac{t_{on}}{t_{cycle}}\right) = \left[\left(\frac{days}{month}\right) * \left(\frac{shifts}{day}\right) * \left(\frac{hours}{shift}\right)\right] * \left(\frac{t_{on}}{t_{cycle}}\right) \tag{4}$$

In equation 4, the $t_{totalmonthly}$ is the average time in which the machines had been in operation during the certain month, the $t_{cycle}$, is the average time of one operation cycle of the electrical heater ton and the is the time during the cycle in which the heater remains effectively connected.

Since the company works in two shifts of 8 hours each, 5 days per week, and considering the average cycle of heaters production of 6s, with a ton ranging from 2 to 3s, it is estimated the consumed energy in the heaters relative to the company's total consumption. (Figure 5).

Therefore it is concluded that the energy consumption in the electric heating varies approximately between 30 to 45% of the total company's consumption. Such percentage proves to be quite expressive and exemplifies the potential impact of this line of research and development, conducted by SCGÁS, in order to amplify the dynamism and competitiveness of the national industry.

The data and the analysis generated from the technical visits enabled the second part of the project: technical-economic evaluation of the technological solutions. It considers, among the project's requirements, that the heat flow for the load should be similar to that in the current equipment.

The fact that the operation of heaters by natural gas presents itself continuously, which implies in periods of functioning without load to be heated, should also be observed. In addition, attention is given to the need of the proposed suggestions to facilitate the installation of the supplying system of natural gas and air, as well as the exhaust system.

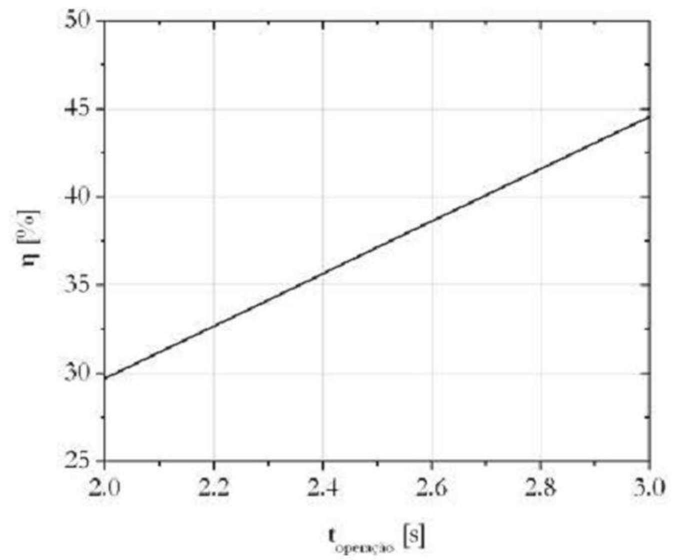


Figure 5: Energy consumed in the heaters, related to the company's total consumption, depending on the operating time

# 3. PROPOSED SOLUTIONS

## 3.1. Methodology

In possession of the data set, both collected in the field as the ones generated by simulations and engineering calculations, the researchers team now proposes technological solutions for the conversion of stamping machines to natural gas. The presented proposals were submitted to a rigorous technical-economic evaluation, and seek the direct replacement of the halogen bulbs heaters and electric heaters into natural gas heaters.

The methodology here involved comprehends an initial thermal evaluation of the systems in operation, to evaluate the rate of heat transfer by radiation from the heater to the textile. Next, is made the use of heat flows of the current process to support the power estimative required in the new configurations of the natural gas machine.

## 3.2. Current equipment: halogen bulbs heater

The thermal model developed for the evaluation of the halogen bulbs heater takes into consideration the transient regime, heat loss due to radiation to the environment and heat loss by convection provided by the ventilators. The measurements were taken under such conditions. In the transient regime evaluation was considered the method of global capacity, disregarding hence the temperature gradients in the lamps. The set of lamps was modeled as an equivalent surface, with mass and specific heat similar to a set of real lamps, and with an average temperature that models the exchange of heat by radiation. It should be pointed out that despite this model being an approximate representation, it allows an enlightening preliminary evaluation of the process.

The radiation was modeled by the radiosity method, considering the material properties of bulbs, pyrex, and the exchange heat to the environment. The heat exchange by convection was modeled through correlations for external drainage, as proposed by Incropera and DeWitt. The average speed of the drainage measured in the heater was 2m/s.

Figure 6 illustrates both, bulbs temperature calculated by the model, as well as the effectively measured; in addition, presents the results of this evaluation and the nominal, total, radiant and convective potencies as well. It is calculated the total potency as the sum of the radiant and convective parcels. The results demonstrated to be in consonance. The measured time for achieving the permanent regime was approximately 70s, while the calculated time was 40s. The permanent regime temperature measured was approximately 430ºC, while the calculated, 470ºC. Such results demonstrate the model capacity to predict qualitatively the thermal behavior of the halogen bulbs.

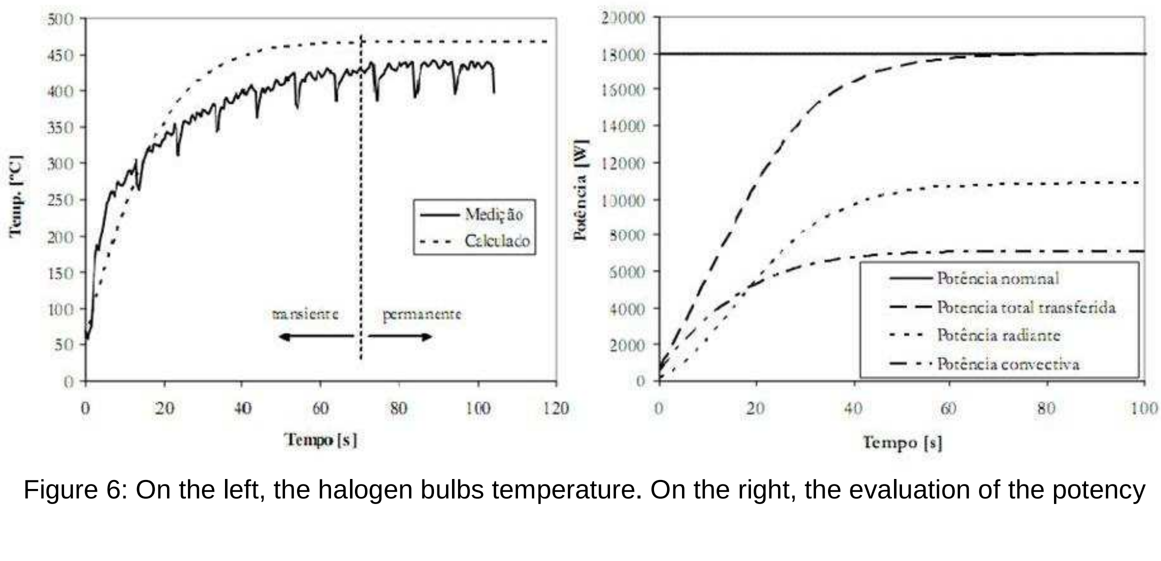


Figure 6: On the left, the halogen bulbs temperature. On the right, the evaluation of the potency

The operation of the halogen bulbs heater is predominantly transient in order to protect the textile support boards. However, average rates of heat transfers were obtained for the models, with the aim of simplifying the process and the solutions supported by them. They were established through the integration of the calculated radiant potency by the halogen bulbs model along the cycle and, subsequently, dividing the potency by the time of the cycle (Table 2). The calculus of the average potencies, radiant ($\mathbf{q_{r,ef}}$) and convective ($\mathbf{q_{ku,ef}}$), considerate their contributions in the 18kW in 2s, followed by the total cycle division, 6s.

| $S_r$ (kW) | $q_{r,ef}$ (W) | $q_{ku,ef}$ (W) | Operation coast* (R$/h) |
|---|---|---|---|
| 18,0 | 2.699 | 3.631 | 1,70 (33% of cycle) |
| | | | 2,60 (50% of cycle) |
| * the electric energy price considered was 0,2889 R$kWh, which corresponds to the average price paid by the textile company in the past 12 months | | | |

Table 2: Averages potencies of the halogen bulbs heater

### 3.3. Proposed solution 1: radiant tubes heater

The "radiant tube heater" solution, figure 7, consists on the halogen bulbs substitution for radiant tube filled by products of the natural gas combustion. The arrangement and the number of radiant tubes follow the same standard as the bulbs heater and, thus, preserve the geometry of the heater in two configurations. The dimensions considered in the techno-economic evaluation are the same as the 18kW bulbs heater.

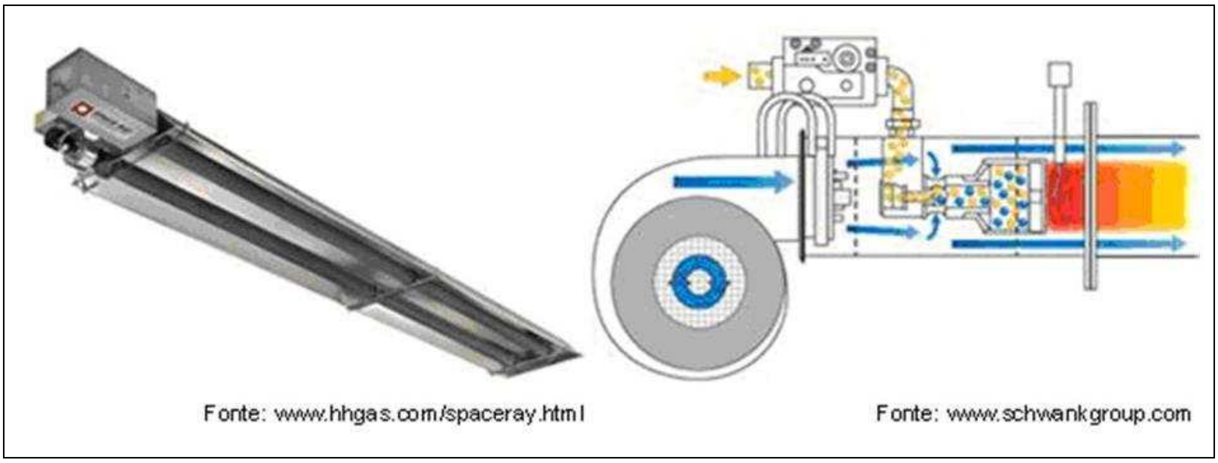


Figure 7: On the left, a radiant type tube burner. On the right, the functional scheme of a radiant tube

The radiant tubes are heated by internal flow of combustion products of natural gas with air. The combustion is made in a separate chamber near by. The flowages in the tubes depend on the combustion power and the excess of primary air. Additionally, it may be included a dilution with cold air to increase the total flowage, aiming to exert greater control over the temperature. The analysis of this first proposal suggested for both regimes, transient and permanent.

For the transient regime, the principle of operation proves to be the same as the halogen bulbs heaters, i.e. the heater is assonated only when the textile heating is necessary. For heating, the internal flow of the combustion products is released through valves. The tubes lose heat by radiation and external convection provided by the ventilators.

There is a thermal model used for evaluate this proposal, which is similar to the one utilized in the halogen bulbs heater, only through the heating tubes modeling for heat exchange with the internal flow of combustion products (Figure 8). For comparative purposes, many types of materials were tested. The temperature considered for the combustion products was 1.000ºC, internal laminar flow, and external flow speed of 2 m/s at 25ºC and heat loss by radiation to the environment also at 25 ºC.

It was noticeable that the material that has the slowest response time for heating is Pirex, which requires approximately 100s to reach the permanent regime at 380ºC. However the cooling process is slow, and requires approximately 140s to achieve 150ºC. The halogen bulbs take approximately 8s to cool: time about 17 times shorter than what can be achieved with radiant tubes. This cooling is extremely important for the protection of the textile support board, assuring that the heater suspension doesn't be necessary. Even when comparing the results of the electric heater model (transient regime of 40s), notices that the radiant tube of Pirex still has a transient regime 2,5 times higher.

This way, it concludes that the use of radiation tube in transient operation seems to be technically impracticable due to the high thermal inertial of the system, which may damage the aluminum board that supports the textile. There haven't been analyzed, consequently, the operational costs of this first proposal in transient regime.

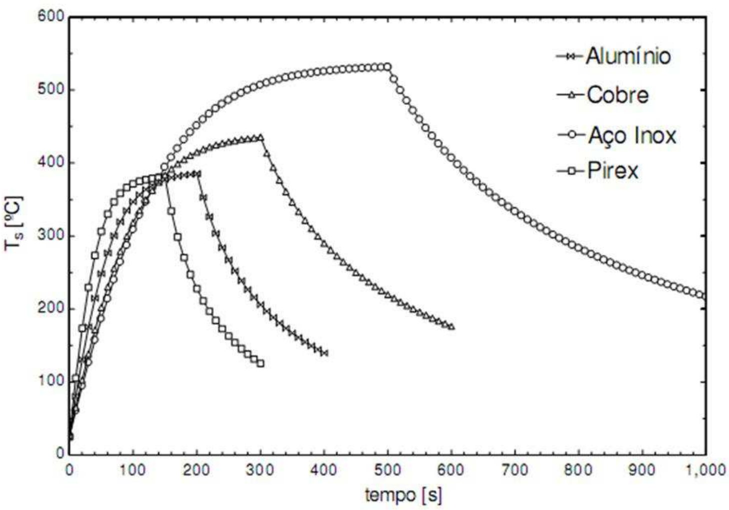


Figure 8: results of the transient radiant tube model

The second regime of operation, the permanent one, does not requires the switching on/off of the heaters during the drying stage. The tube is heated continuously through the internal flow of the combustion products. This configuration result in the heat loss by radiation to the environment at 25º C and by convection by the cold air flow proportionate by the ventilators. The thermal model utilized for evaluating is the same as used in the proposal of transient radiator tube. As mentioned earlier, the results of the average exchanging heat taxes, calculated in the halogen bulbs heater, were used as input parameters for this model. Thus, it was possible to estimate the required power of the natural gas combustion process, to keep the operating conditions of this proposal equal as the average conditions of the halogen bulbs heater. There were realized two costs analysis, one considering the stainless steel and the other considering the refractory ceramic as the tube material. The main difference consists in the temperature of the combustion gas that each material supports. Are exposed in table 3 the main data of this analysis, using for the natural gas rates the ones charged by SCGÁS.

| Tube Material | Temperature of the combustion gases (ºC) | Operating Power (kW) | Efficiency (%) | Natural gas flowage ($m^3$/24h) | Operating costs (R$/h) |
|---|---|---|---|---|---|
| Stainless steel | 1100 | 28,3 | 9 | 68,6 | 3,2 |
| Ceramic | 1500 | 11,3 | 23 | 27,4 | 1,25 |

Table 3: Results of the radiator tube solution in the permanent regime

### 3.4 Proposed solution 2: Porous Radiant Burner Heater

This solution consists in building a heater with radiant porous burner technology. The quantity, arrangement and operation of theses burners rely on refined thermal project, which takes under consideration, among other aspects, the homogeneity of temperature required in the load, the load/burners distance and the inclusion of radiation reflectors as well. The operating costs in permanent regime were estimated (table 4) to produce the same radiation potency as those calculated in the halogen bulbs model.

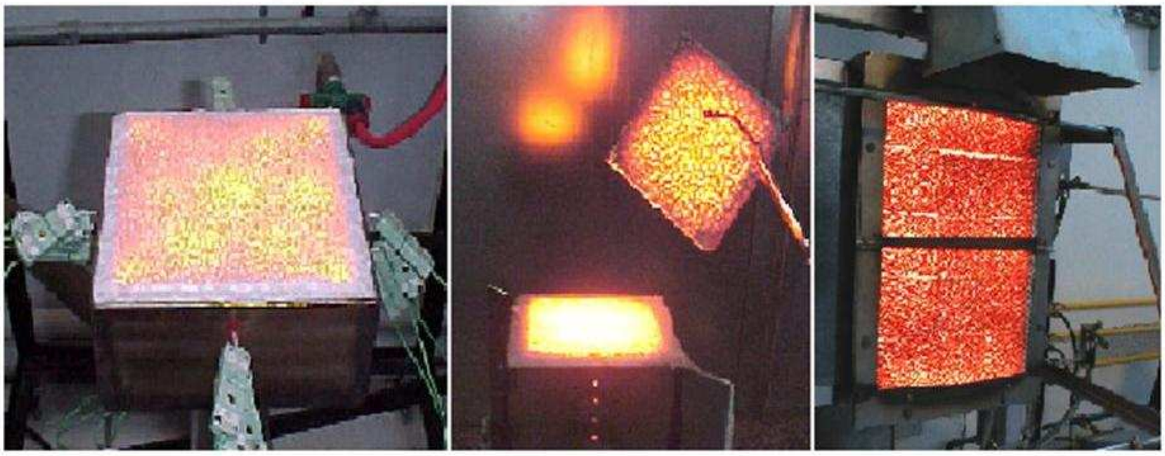

Figure 9: Examples of porous burner (LabCET – UFSC)

| Operation power (kW) | Efficiency (%) | Natural gas flow ($m^3$/24h) | Operating costs* (R$/h) |
|---|---|---|---|
| 9,0 | 30 | 21,8 | 1,00 |
| *the utilized natural gas price for the calculus was 1,1106 R$/$m^3$ | | | |

Table 4: Results of the radiant porous burner solutions

Additionally, the use of radiant burners allows the transient operation, once they feature a rapid cooling after being turned off. These arrangements may facilitate the operation and eliminate the need of the burner articulation to protect the textile support. Such characteristic, requested by the operators, provides greater security and facilitate operating the system. To calculate the cost of operation, the model considered the ignition of the system, usually made in higher potencies than the workload, as well as the time when the system is shut down to protect the supporters.

## 4. EVALUATION OF TECHNICAL-ECONOMIC SOLUTIONS

Table 5 shows a comparison between the main technical-economic characteristics of the proposed solutions. For purpose of comparison, the characteristics of the 18kW halogen bulbs heater are also presented. It is observed that initially the cost of operation for halogen bulbs heater ranges from R$ 1.70 to R$ 2.60 per hour depending on the cycle time. The proposed solution "radiant tube heater" has a higher cost of operation for the tubes made of stainless steel, around R$ 3.20. As for the ceramic tubes this solution has become more competitive, with an operating cost of R$ 1.25. The solution "porous radiant burner heater" has the lowest operating cost per heater, around R$ 1.00 per hour.

| Requirement | Halogen bulbs | Radiant Tube | Radiant Burner |
|---|---|---|---|
| Potency (kW) | 18 (electrical) | Stainless steel: 28,3 | 9,0 |
| | | Ceramic: 11,3 | |
| Operating costs per heater (R$/h) | 1,70 (33% cycle) | Stainless steel: 3,20 | 1,00 |
| | 2,60 (50% cycle) | Ceramic: 1,25 | |
| Efficiency in radiation (%) | - | Stainless steel: 9 | 30 |
| | | Ceramic:23 | |
| Local emission of pollutants | Null | Intermediate | low |
| Regime of operation | Transient | Permanent | Permanent |
| Allows transient operation | Yes | No | Yes |
| Contact of combustion products with the piece | - | No | Yes* |
| Modifications on the current form of operation | - | Yes | Yes |
| Need for articulation of the heater | No | Yes | No (transient regime) |
| *may be avoided by using the auxiliary ventilators | | | |

Table 5: Main technical and economic characteristics of heating current and proposed solutions

Based on the number of existent heaters, the number currently being installed in the company and considered a 24 hours operation per day, it was estimated the potential consumption of natural gas for each of the proposed solutions:

A) Stainless steel radian tube – 6.355 m³/day;
B) Ceramic radiant tube – 2.538 m³/day
C) Radiant burner – 2.020 m³/day

## 5. CONCLUSIONS

This research project developed by SCGAS generated valuable data about the implementation feasibility of improvements in the textile industry, from technical solutions based on the use of natural gas. The information contained here constitute the basis for serious and insightful decisions to be taken. They provide grants to entrepreneurs in the industry to give a competitive advantage to their business. The choice of a technological differential that provide the production process such cost reduction translates directly into financial return. The partnership in the development of new technologies, as well as pioneering in their applications, contributes to the positioning of a company as a leader in your industry. Besides the advantages already mentioned by the proposed solutions, another of considerable importance refers to environmental impacts. The use of electricity, considered a prime input, for thermal electrical generation is one of its worst possible applications. The substitution of electricity by natural gas in this context contributes to greater sustainability and efficiency of the economy as a whole.

In conclusion, the paper presents two viable solutions extremely interesting for the companies in the textile sector: the "ceramic radiant tube heater", which represents a reduction in operating cost of 42%, with estimated consumption of natural gas around 2.500m³ / days, and "radiant burners heater," which represents a reduction of 54%, with estimated consumption of 2.000m³/dia - for the case study.

To finalize, Figure 10 presents some comparative data of projected savings and differences in the operational cost per hour. The comparison was made in relation to the electrical system of halogen bulbs at a cost of approximately R$ 2,15, the average between R$ 1,7 and $ 2,6 presented earlier for the two types of cycle.

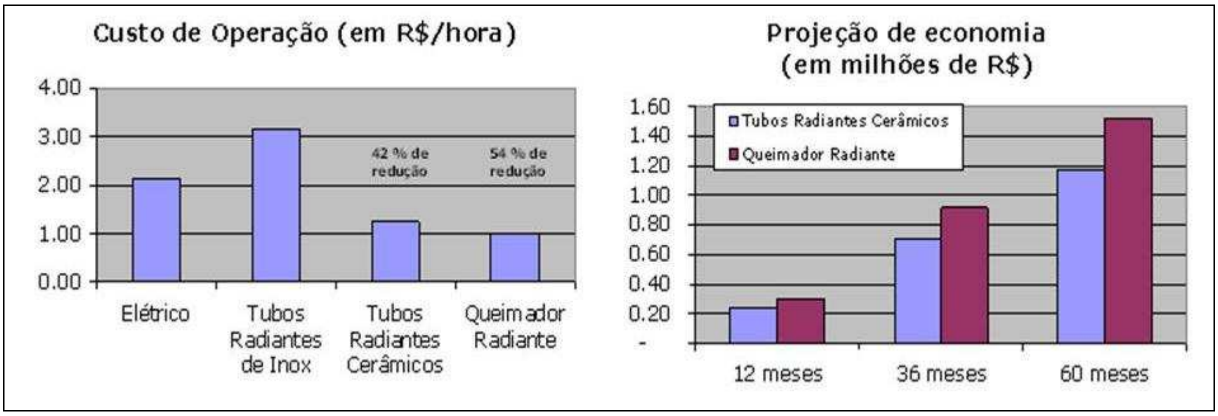


Figure 10: On the left, operational costs per hour. On the right, the projected savings

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