GRI – 02/0133

Field Evaluation of Gas-Fired Infrared Systems for Cocoa Beans Drying

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For

GAS RESEARCH INSTITUTE

Contract No. 6004

GRI Project Manager
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13. ABSTRACT (*Maximum 200 words*)

The report describes the use of a gas infrared heating system for drying cocoa beans used in processing chocolate products. A new metal fiber type IR system was compared with an existing ported ceramic tile type heater. Results were inconclusive as both systems provided acceptable product quality, similar heating profiles and production rates and operational flexibility. Methods to optimize the heating system such as speed and loading, distance between heater and product, and heating profile optimization could not be performed in the production test environment selected.

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RESEARCH SUMMARY

Title	Field Evaluation of Gas-Fired IR Systems for Cocoa Beans Drying
Contractor	SS Energy Environmental International, Inc.
GRI Contract Number	6004
Principal Investigator	Shyam N. Singh
Objective	To evaluate a metal fiber-type gas infrared heater system in a cocoa bean processing system and to compare it with the baseline system using a ceramic ported tile-type gas infrared heater. Product quality, heating profile and energy consumption are to be evaluated.
Technical Perspective	Infrared heating is potentially a flexible tool that can have wide multi-function application in food processing. For example, IR can be used in preheating, drying, or to impart specialized appearance or physical characteristics to the food product. Food processors require more information on operation of IR systems and on the practical differences, if any, between available product options. The purpose of the field trial was to evaluate the potential benefits of using IR in food processing and to determine if significant differences in performance could be identified in a production environment between two types of gas-fired IR heaters. The cocoa bean processing system studied provided an opportunity to evaluate and compare two gas-fired infrared heating systems used for preheating and predrying. This process is necessary to prepare the cocoa beans before removing the shells in the winnower and roasting. An adequate processing requires producing an optimized temperature to prevent burning while properly straining the shells thermally. It also requires proper moisture content, and flavor retention control in the beans.

Technical Approach

For the purpose of this study, an existing IR heating system was replaced on one production line with a metal fiber-type IR drying system. ADM, the field host site, used ported ceramic-type IR heaters for drying their cocoa beans on the second parallel production line.

Knitted metal fiber selected for the new IR heaters was configured to match the footprint of the dryer. The proposed metal fiber heaters were all rated at 30,000 Btu/hr/ft^2 capacity resulting in 750,000 Btu/hr total input for the system. The new system had ten (10) heaters having 6"x42" dimensions, each heater ignited by its own spark rod, and each having its own flame sensor. The adjustable heaters faced downwards at a height of 9" from the vibrating table carrying the beans. Majority of the time the heaters were run at high fire with slight change in input due to change in the cocoa bean feed rate controller integrated with the existing master controller designed to control the feed rate, firing rate and other auxiliary control components. Data was collected at the site.

Results

Over a period of three months, different types of cocoa beans were processed through the dryer. An initial test period resulted in lower thermal efficiency for the metal fiber-type IR system, however adjustments brought it into equal, or slightly better thermal efficiency as the ported ceramic tile. Neither system was optimized during their data collection period since it was done in a production environment and there was a concern that other equipment downstream of the dryer might be adversely affected.

The moisture content of the beans processed in both new and old heating systems were similar. A visual observation of the beans showed an improved quality in that fewer beans breakage and less charring of the shells occurred in the new metal fiber IR system. The beans shells also seemed easier to peel off by hand but these observations were not measured in a quantifiable manner. Unlike in the old system where the light-off starts at both ends and propagate towards the center, the new system was judged to have an easier light-off since individual heaters are fired simultaneously.

The results for this project indicate that either metal fiber or ported ceramic tile IR heaters can be used with roughly equivalent results in this food processing application. Both systems met production rate, moisture content, and product quality requirements. Durability and replacement cost differences were not evaluated.

Project Implications

Additional information was documented on the efficient use of gas infrared heating as a flexible tool in the food processing industry. This information can be used by food processors evaluating the application of infrared heating for multi-purpose applications including preheating, drying, and specialized heating.

Project Manager

Stephen J. Sikirica

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1. INTRODUCTION

1.1 Project Background

Under the original contract, SSEEI proposed to evaluate gas IR heaters in a food processing application. After several sites were evaluated agreement was reached with ADM to do an evaluation in a cocoa bean operation. ADM is one of the largest producers of food products. They process cocoa beans for chocolate production.

The processing plant is located at 12500 West Carmen Avenue, Milwaukee, Wisconsin and served by Wisconsin Energy Corporation (WEPCO & WGC). They process about 24,000 tons/yr of cocoa beans ranging from vibrant red beans to dark brown beans with different fat contents and degrees of alkalization for chocolate production. The predryer runs 24 hrs a day, seven days a week throughout the year.

The plant uses two predryers in parallel processing lines that were originally equipped with gas fired ceramic radiant heating systems. A preliminary examination of the existing systems was conducted prior to selection of the new IR system for one of the lines. Following is a brief description of the process and related concerns.

During the production, it is important to produce consistent open shell beans without burning. There are several steps involved in producing the final products, one of which is predrying of the beans. Predrying takes place at the early stage of the production. This process is necessary to prepare the beans before removing the shells in the winnower. An adequate drying must produce an optimized temperature, moisture content and flavor retention in the beans.

1.2 Objectives

The overall objectives of the proposed efforts were to:

1. design a retrofittable metal fiber-type gas IR heating system that could be easily installed within the existing foot print
2. evaluate the new heater system and compare it with the baseline system using a ceramic ported tile-type gas infrared heater in terms of product quality, heating profile and energy consumption.

1.3 Process Description

The cocoa beans are fed onto a vibrating table, which passes through a 22 ft long oven called a "Predryer" drying. Thereafter, the dried beans are conveyed into a winnower to remove and separate the shells. The beans are roasted to achieve desirable properties. During roasting, volatile organic compounds (VOC's) are released, which are then processed in a thermal oxidizer in order to meet the EPA and State regulated compliance limit. Figure 1 shows a simplified schematic diagram of the process.

The cocoa beans are heated from the top by gas IR heaters. However, these heaters appear to provide uneven temperatures which cause some beans to be overcooked or burned and eventually get rejected.

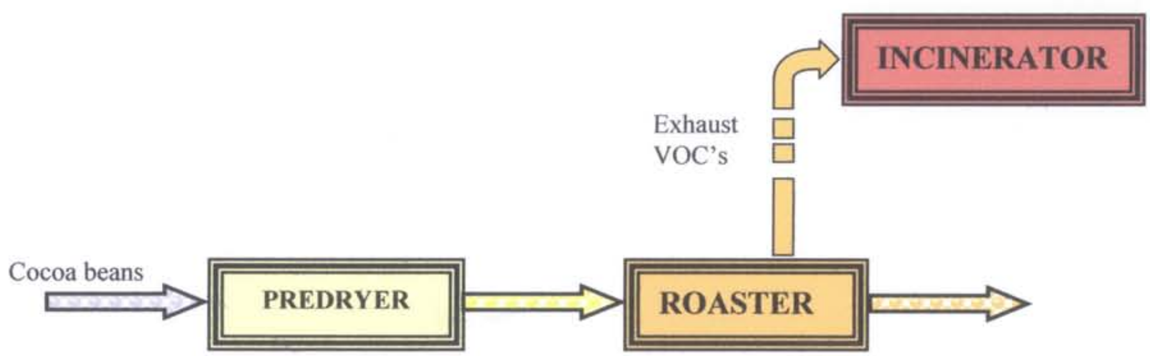


Figure 1. A Schematic of Process Flow through Predryer, Roaster and Thermal Oxidizer

1.3.1 Existing Burner System

The 22 ft long oven (see Figure 2) has a heating system consisting of 40 IR heaters manufactured by Rinnai #R1603-2 having size 20" x 3½". The heaters/burners are made of ported ceramic tiles. They operate at 3 to 1 turn-down ratios. Total heat input to the system is approximately 990,000 Btu/hr. The input to the burners is controlled in a high and low mode.

The heaters are installed on a 47" x 180" frame in two rows as shown in Figure 3 and the whole unit is mounted on springs over the vibrating table. Raising or lowering the support frame can vary the distance between the heaters and the vibrating table. Natural gas/air mixture is distributed through the main rectangular manifold that supplies the individual burner rows. The exhaust gases are carried away through the extraction canopy.

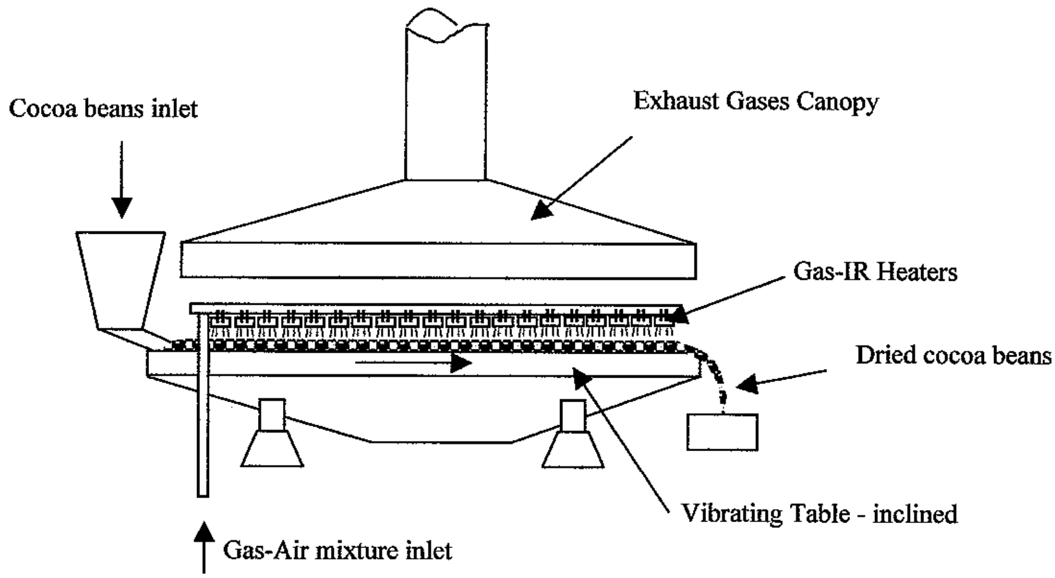


Figure 2. Schematic of the Predryer

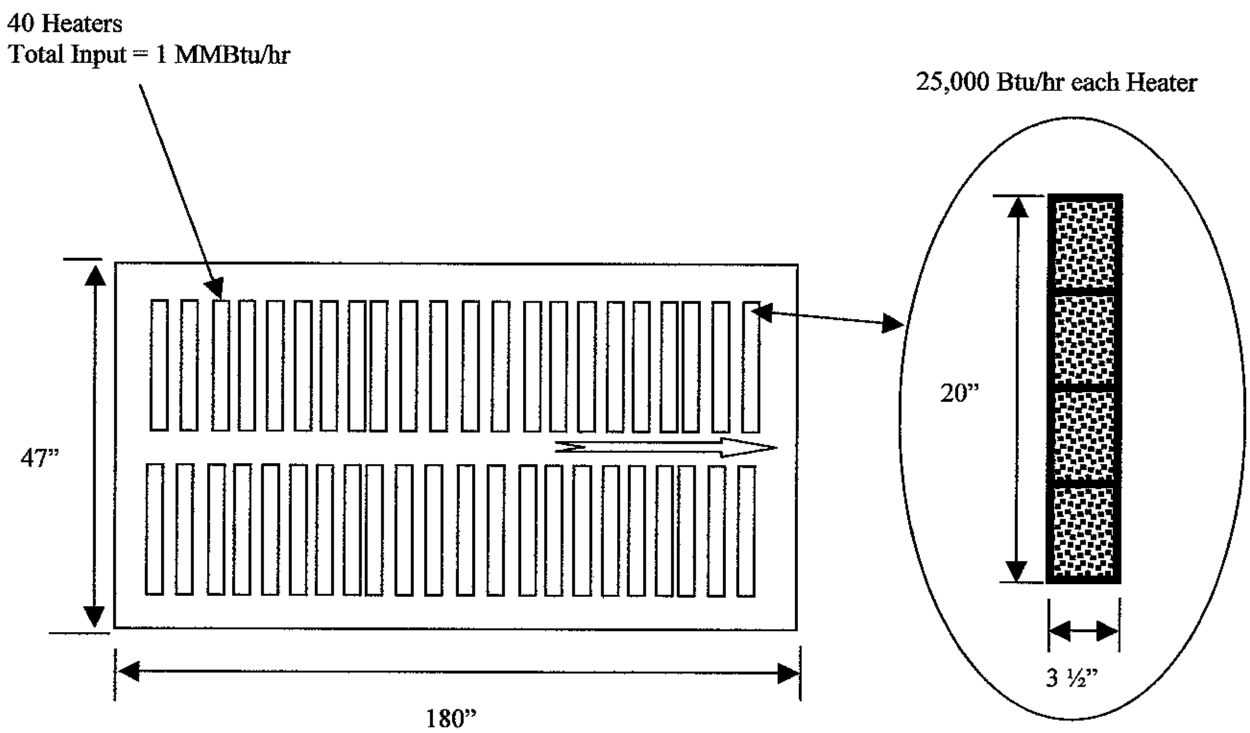


Figure 3. Schematic of the Existing Gas IR Heating System in the Predryer

1.3.2 Operating Data

Cocoa beans are imported from various countries. The virgin beans are in oval shape, as shown in Figure 4 with ½" x 1" dimension and weigh about 0.0022 lb, each. The production rate varies between 6,000 to 9,000 lbs/hr. Currently, they operate either both dryers or operate intermittently to satisfy fluctuating productions demands.

After drying, the cocoa beans split and break into small pieces (see Figure 5) a situation that is undesirable because the light pieces get aspirated with the shells in the winnower. It would be desirable that the beans remain as such with only the shells splitting off. This would reduce losses due to winnowing. Figure 5 shows burnt beans during the process of drying. Overheating and non-uniform heating can also cause this to occur.

Moisture content of beans before predrying	4 - 7 %
Moisture content of beans after predrying	0.6 - 1.0 %
Beans speed on the vibrating table	0.15 - 0.25 ft/s
Beans feed rate (Average)	3,500 - 6,500 lb/hr
Heat input	990,000 Btu/hr
Bean retention time inside the dryer	60 - 90 seconds
Travel distance in the dryer	180"
Operating temperature of the dryer	350°F

Table 1. Operating parameters of the dryer

Figure 4. Cocoa beans with oval shape before processing in predryer

Figure 5. Dried beans with split shells and broken beans after predrying

2. TECHNICAL APPROACH

2.1. Proposed Gas IR Metal Fiber Heater System

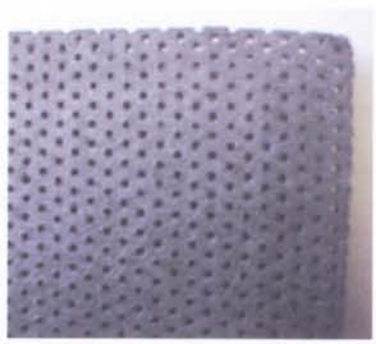
From the examination, it was concluded that very limited operating data were available regarding the IR heaters' performance. This warranted an onsite data collection of important operating parameters that would help in designing the proposed gas IR system. The operational examination included firing rate, beans properties and combustion products.

As described earlier, a properly designed metal fiber IR heaters would reduce the temperature non-uniformity and would eliminate the ceramic thermal fatigue problems of the IR heater. In addition, the metal fiber heaters would offer more flexible turn-down capabilities often lacking with the ported ceramic IR heaters.

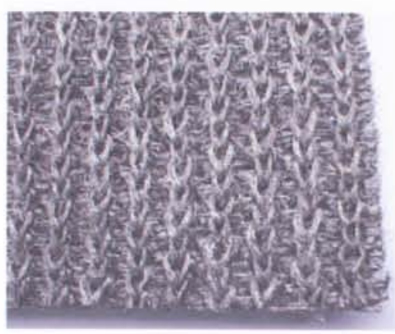
The proposed metal fiber emitters are manufactured using Fecralloy which is a refractory steel highly resistant to oxidation at temperatures over 1,800°F. The fibers are knitted together to produce a flexible, highly porous mat which is used as an emitter. The mat requires a ported deck support of any shape. Typical metal fibers are shown in Figure 6 and a schematic of the burner is illustrated in Figure 7.

This heater can operate at 6 to 1 turn down ratios or even higher in special cases. One of the unique features of this burner is rapid heating and cooling rate which is always desirable when production has to run without delay in heating the oven. In addition, the radiant surface material is highly corrosion resistant resulting in a prolonged useful life. Due to quenching effect of highly radiant surface, flame temperature is quenched, producing less than 15 ppm of NOx at 3% O_2.

a) Sintered metal fiber



b) Perforated sintered metal fiber



c) Woven sintered metal fiber

NOTE: Used in the proposed Gas IR heater

Figure 6. Typical metal and ceramic Porous Materials

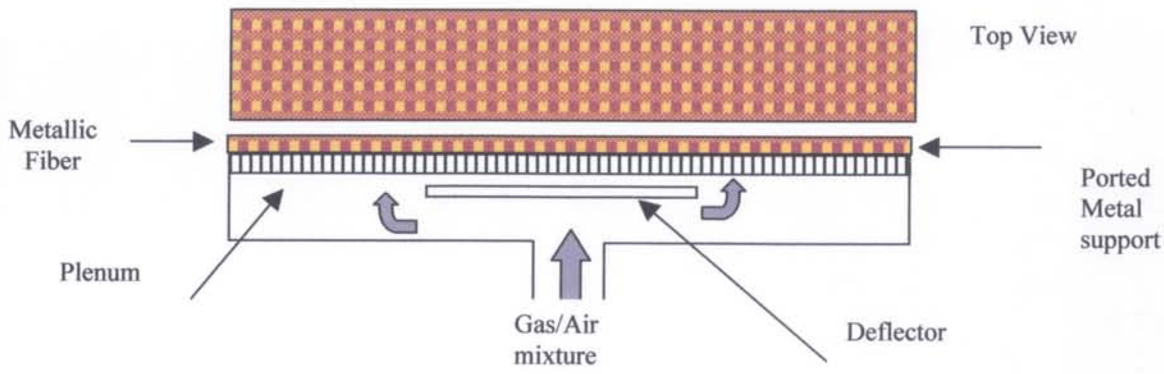


Figure 7. Metal Fiber Surface Combustion Burner

2.2 Heater System layout

To maximize the use of the footprint of the dryer/heater system, three different heater system layouts were considered. Each option is described below.

2.2.1 Heater System layout – Option I

This option consists of ten (10) 6" x 42" metal fiber heaters rated each at 75,000 Btu/hr making a total of 750,000 Btu/hr. A schematic of the heater arrangement is shown in Figure 8.

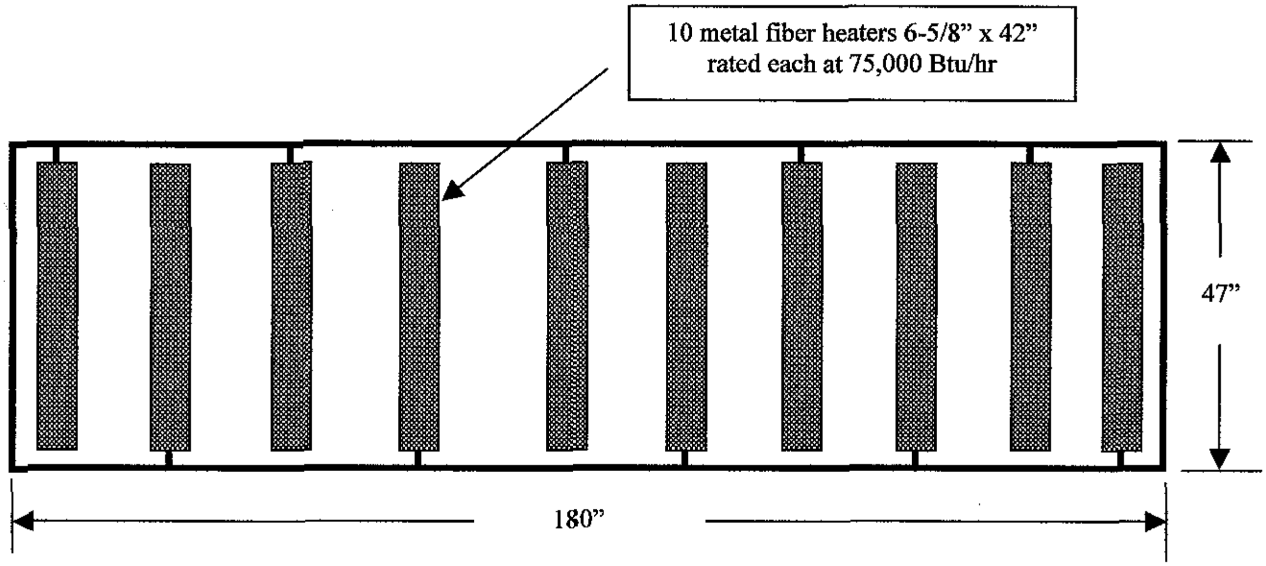


Figure 8. Schematic of IR heater arrangement – Option I

2.2.2 Heater System layout – Option II

Option II consists of eighteen 6 $^5/_8$" x 24 ½" metal fiber heaters rated each at 40,000 Btu/hr making a total of 720,000 Btu/hr. A schematic of the heater arrangement is shown in Figure 9.

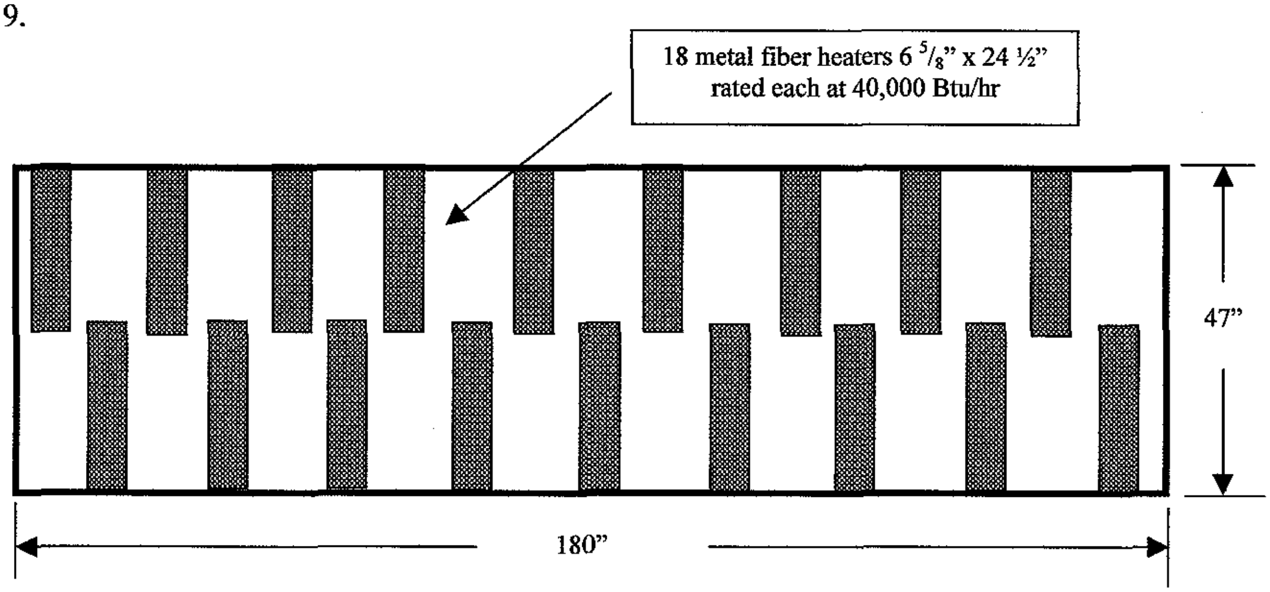


Figure 9. Schematic of IR heater arrangement – Option II

2.2.3 Heater System layout – Option III

This option consists of ten 5" x 42" metal fiber heaters rated each at 60,000 Btu/hr and fourteen 5" x 12" metal fiber heaters rated each at 10,000 Btu/hr making a total of 740,000 Btu/hr. A schematic of the heater arrangement is shown in Figure 10.

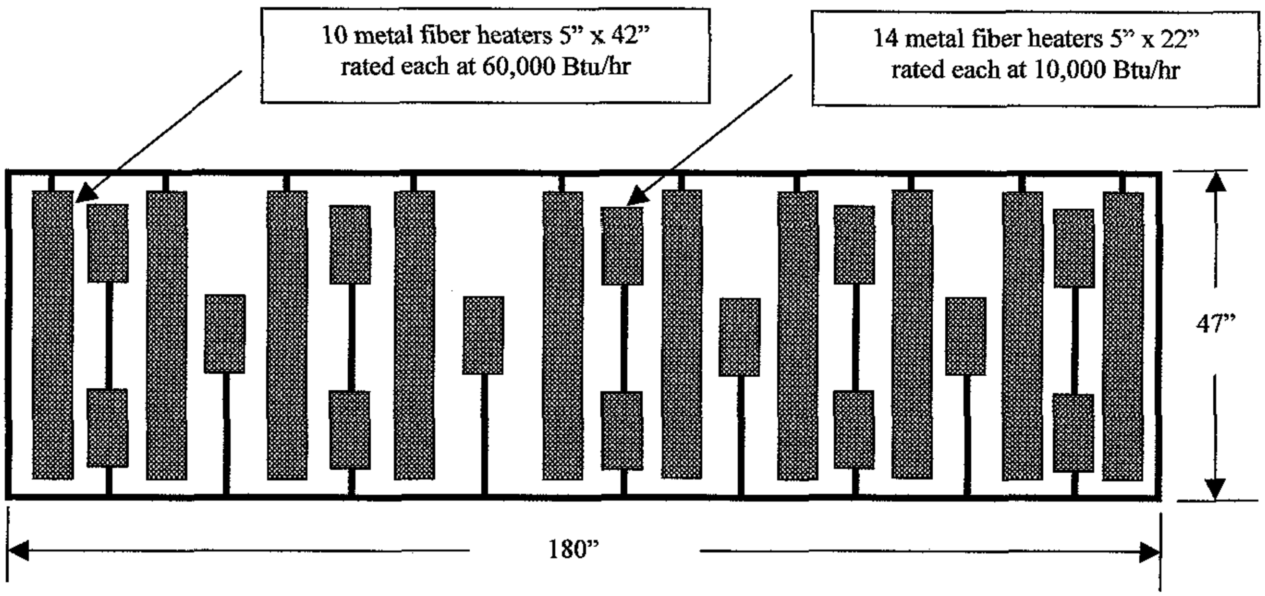


Figure 10. Schematic of IR heater arrangement

2.2.4 Heater System layout – selection

There are advantages and disadvantages of these three options. First option eliminates a large number of manifold requirement, reduces installation and service cost. However, it might not offer optimum temperature uniformity. The second and third options may require more manifolds, higher installation and maintenance costs but provide better temperature uniformity. In addition to the turndown capability, lower demands can be taken care of in Option III by shutting off the smaller heaters (14 of them) attached to one side of the frame. These design criteria were reviewed by the host. At the conclusion, OPTION I was selected due to its cost effectiveness and easier installation.

The new system would consist of 10 metal fiber IR heaters, each having a dimension of 6" x 42" x 3" and a firing rate of 30,000-150,000 Btu/hr/ft^2. The inlet air/fuel mixture will be located at the center back of the heater, to achieve uniform flow distribution.

Based on the selected heater layout, the following list of equipment and design criteria provides the details of the components. There are added features to our system to overcome any unsafe operations, i.e. each burner manifold would have its own flame rod and flame ignition device.

2.2.5 System components including heaters & control panel

A. HEATERS

- A.1. Metal fiber heaters 6" x 42" x 3", Firing rate 30,000-150,000 Btu/hr/ft^2 (10 pieces)
- A.2. Flame rods (10 pieces)
- A.3. Ignition devices (10 pieces)

B. MOUNTING FRAME

- B.1. Angle Iron Frame Assembly (1 piece)
- B.2. Load height adjusting legs
- B.3. Heater mounting supports
- B.4. Perforated flashing between heaters
- B.5. Air/gas mix supply header
- B.6. Stainless steel flashing along two side walls

C. FLAME SAFETY CONTROL PANEL

- C.1. NEMA 12 Enclosure (1 piece)
- C.2. 120 V primary fusing
- C.3. Honeywell 7800 series flame relay, bases, amp cards (10 pieces)

C.4. Honeywell display cards (1 piece)

C.5. 120 V fusing (one per flame relay) (10 pieces)

C.6. Ignition contactor (2 pieces)

C.7. Plexiglass front for relay visual access

C.8. Terminals (50 pieces)

C.9. Control relays (10 pieces)

C.10. 120' High temperature ignition cable

C.11. Ignition transformers with rajah connector (10 pieces)

3. DATA ACQUISITION AND ANALYSIS

3.1 Energy Usage

The natural gas consumption was recorded for both Predryers A and B for about one month. The data obtained are displayed in Table 2.

Two distinct periods:

Fine-tuning was made on the new heater system on 2/21/02. Before then, meter readings were generally higher for the new system except on Feb 11 when consumption was lower by 40%. This result is shown in Figure 11.

As from 2/20/02, lower gas usage was recorded for the new heater system (see Figure 12), though the last two days were slightly higher.

In Table 3, the data were split into the two periods identified above, and added up. Each period represents about 200 hours production run. Before fine-tuning, natural gas consumption was higher by 28% in the new system but this dropped to 6% lower usage after fine-tuning.

Possible reasons for this observation could be:

- Variation of the bean properties
- Excess air in gas/air mixture causing surface temperature to go down and thus require more gas to raise the surface temperature.

Bean Type	Date	Hours-A	Hours-B	Usage A ft^3	Usage B ft^3	A - CFH	B - CFH	% diff.	
Ivory	11-Feb	59.8	55.8	36,717	49,662	614	890	45	
Ivory/Indo	11-Feb	5.7	5.6	4,543	2,677	797	478	-40	
Indo	12-Feb	8.9	7.8	5,919	7,332	665	940	41	
Arriba	12-Feb	6.1	4.5	4,337	3,929	711	873	23	
Arriba/Ivory	13-Feb	12.5	12.5	9,063	11,025	725	882	22	Before Tune-up of heaters
Ivory	14-Feb	11.5	11.5	8,637	10,753	751	935	25	
Ivory	15-Feb	17.8	18.3	13,706	15,592	770	852	11	
Ivory	18-Feb	58.4	51.6	40,588	47,627	695	923	33	
Ivory	19-Feb	21.3	18.1	16,891	16,417	793	907	14	
Ivory	20-Feb	17.1	20.4	15,527	16,891	908	828	-9	
Tuned	21-Feb	12.9	13.6	10,707	10,839	830	797	-4	
Ivory	22-Feb	12.7	12.4	10,884	9,573	857	772	-10	
Ivory	22-Feb	6.9	6.8	5,382	4,801	780	706	-9	
Ivory	25-Feb	50.4	49.1	43,848	37,021	870	754	-13	
Ecuad	25-Feb	4.9	4.9	4,356	4,101	889	837	-6	
Indo	26-Feb	12.6	11.8	11,705	10,443	929	885	-5	After Tune-up of heaters
Indo	27-Feb	15.8	16.1	14,283	13,105	904	814	-10	
Ivory	28-Feb	9.9	16.9	9,167	13,774	926	815	-12	
Ivory	1-Mar	16.7	18.5	15,191	14,948	908	808	-11	
Indo	4-Mar	60.6	56.0	45,677	45,080	754	805	7	
Ecuad	5-Mar	11.9	11.8	9,699	9,700	815	822	1	

Table 2. Gas consumption data in Predryers A and B (data supplied by ADM)

Predryer A: Existing Heater System
Predryer B: New Heater System

Dates	Hours-A	Hours-B	Usage A ft^3	Usage B ft^3	A - CFH	B - CFH	% diff.
2/11 to 2/19	**202**	**186**	**140,400**	**165,012**	**695**	**889**	**28**
2/20 to 3/5	**232**	**238**	**196,426**	**190,276**	**845**	**798**	**-6**

Table 3. Cumulative Gas Usage data in Predryers A and B (extracted from Table 2)

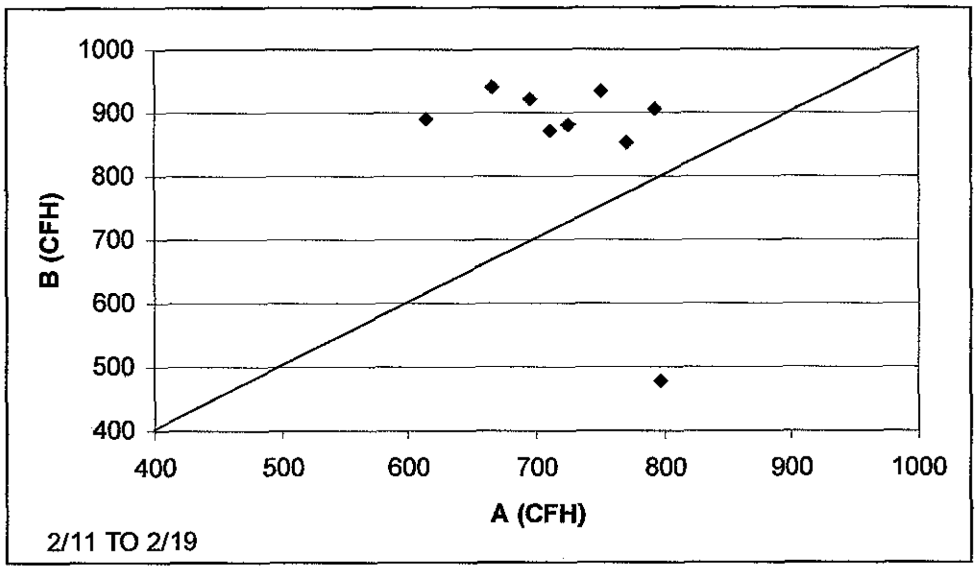


Figure 11 Gas Usage in Predryers A and B from Feb 11 – 19.

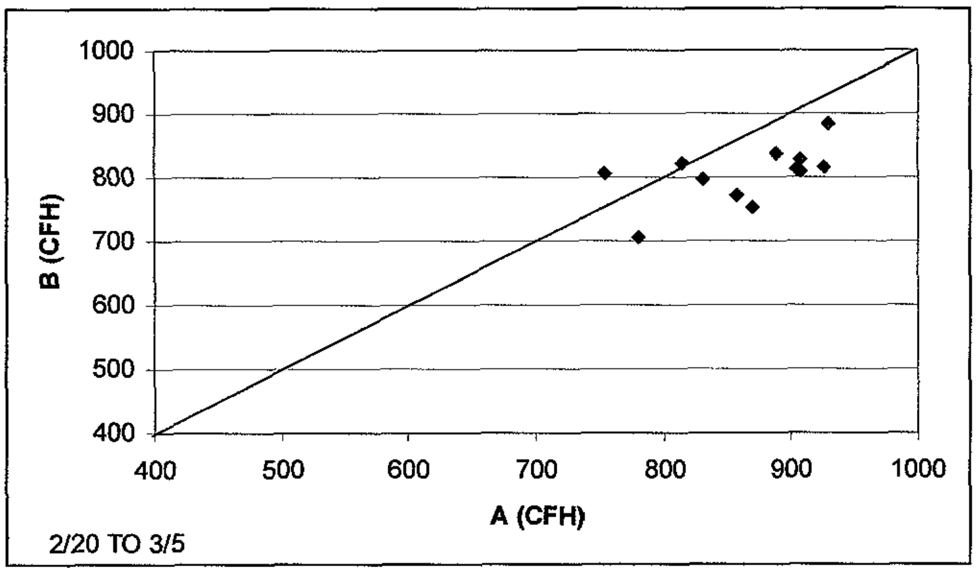


Figure 12 Gas Usage in Predryers A and B from Feb 20 to March 5.

3.2 Temperature Profile

Temperature profiles in both predryers show the same pattern as shown in Table 4 and Figures 13 and 14. However, there is a slight difference towards the exit of the beans from the predryers. Lowering of the beans temperature begins earlier in the new heater system (line B) than in line A. This happens over the last 30" of travel on the vibrating table and may explain why line B does not meet the temperature set point. This should not affect the drying quality of line B, however.

Distance (in)	Temperature (°C) 2/21/02		Temperature (°C) 2/26/02	
	Micro. A	Micro. B	Micro. A	Micro. B
0	25	25	25	25
9	66	50	60	50
18	75	80	60	85
27	80	85	85	80
36	110	105	99	105
45	110	125	105	105
54	120	130	110	135
63	140	130	120	125
72	145	150	130	145
81	145	145	140	155
90	150	170	165	175
99	175	160	155	160
108	185	180	160	170
117	185	180	175	165
126	180	180	185	175
135	190	180	190	160
144	185	185	195	165
153	190	180	195	170
162	185	160	190	175
171	180	160	180	165
180	170	160	175	160
189	170	140	175	150
198	100	92	100	93

Table 4. Temperature Profile of Tumbling Cocoa Beans in predryers A and B

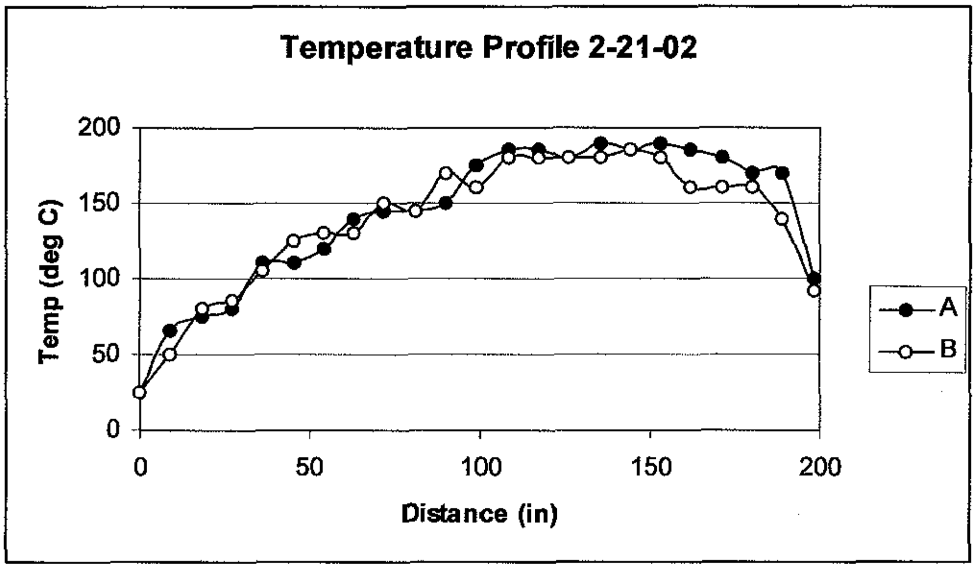


Figure 13 Temperature Profile of Tumbling Cocoa Beans in Predryers A and B measured on 2/21/02

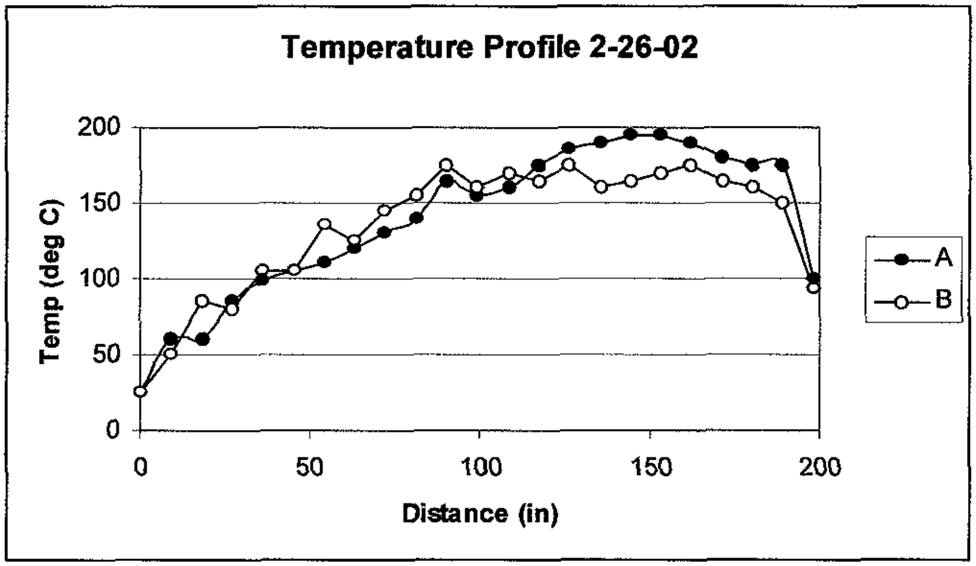


Figure 14 Temperature Profile of Tumbling Cocoa Beans in predryers A and B measured on 2/26/02

3.3 Moisture Content

DATE	INLET	EXIT FROM A	EXIT FROM B
2/21/02	6.40%	4.76%	4.84%
2/26/02	7.61%	5.03%	4.80%

O_2 in flue gas		2%	2%
Beans Feed Rate	Feed roller setting 8	About 3,000 lbs/hr	About 3,000 lbs/hr

Table 5: Moisture content and percentage oxygen in exhaust gases

3.4 Problems encountered

There were a few problems encountered in the installation and operating the system.

(a) When burners were too close to the table (about 6"), the beans shells were igniting causing concerns. However, this problem was immediately rectified by raising the burner support to a height of about 9" from the vibrating table.

(b) The support structure, upon which the burners were bolted, had both ends welded to the main frame. During operation, the structures got heated up and warped since there was no room for expansion. The individual burners themselves remained horizontal as they were bolted at the center. When the system was stopped and cooled down, contraction made the structure to go back to its original state. This caused some concern of failure due to fatigue. After careful examination, we determined that only one end of the support would be welded and the other end left free to expand.

(c) Due to operational concerns, other equipment directly connected to the predryers dryer, we were unable to optimize the distance between the heater and the cocoa beans. This may be the sole reason that we could not achieve targeted fuel savings of 25%.

3.5 Payback

Based on design parameters, our study reveals that there is a potential to save 17,850 Therms/year from dryer by using a new and improved gas IR heater system. The new burner system including material and installation came up to a total cost of $30,375.00.

In summary:

	Cost of Unit $	Savings		Payback Years
		$	Therms/yr	
Burner system and installation	$30,375.00	$8,925.00*	17,850**	3.4 years

** based on $0.50/therm ** assuming existing heater rating of 990,000 Btu/hr and 8,500 hr annual operation*

4. CONCLUSIONS AND RECOMMENDATIONS

Based upon three weeks of field evaluation of the metal fiber heaters, we conclude the followings:

1. Natural Gas Usage

A slight reduction in natural gas usage was recorded with the new heater system compared to the plant's existing ceramic gas IR heater system, especially after tune-up of the new system.

We believe that the percentage reduction in gas consumption can go up to 20 to 25% if the following actions could be taken:

- install screens at both sides of the heater system. This does not only reduce heat loss from the sides but also promotes re-radiation towards the tumbling beans
- lower the heater to an optimal height to avoid the integrity of the vibrating table or fire hazards. This is important because the heat transfer mode is by radiation and the distance between heater and beans is a critical parameter in assessing the maximum heat transferred to the beans.
- the processing plant could also consider increasing the through put of cocoa beans through the predryers. Of course, the maximum effective bulk beans layer thickness of 1½" on the table must be respected by varying the table inclination and the feed roller setting.

2. Temperature Profile

Temperature profile and residence time are important parameters in the drying process. The temperature profiles on both predryers show a similar pattern. The plant needs to define what objective they wish to obtain by the predryer:

a. Heat the beans to a given exit temperature

   If this is the objective, then the temperature profiles reveal that this condition is reached midway through the travel. Speeding up the feed rate can be a means of lowering the maximum temperature.

b. Dry the beans to a specific moisture content

   Intensive data collection is required to correlate change in moisture content with residence time, cocoa beans feed rate, drying temperature, heater/load distance, etc.

c. Both (a) and (b)

   The required exit temperature can be kept fixed and all the other parameters varied to optimize moisture desired.

3. Moisture Content

There was no significant difference between the moisture content of cocoa bean samples taken from the exits of both predryers as shown in Table 5. This was expected because of the similarity of the temperature profiles and other operating conditions such as the feed rate. The exit moisture content will depend on cocoa inlet conditions, feed rate, heater/beans distance, etc.

4. Other parameters to investigate

Since the objective of this project was to reduce energy usage or increase production and to improve or maintain the quality of the dried cocoa beans, the plant needs to define other parameters that are vital in determining the quality of the beans dried in the predryer. Such parameters may include:

- beans breakage
- volume expansion
- exhaust gas composition: CO/CO_2, O_2, UHC, NOx
- color
- aroma

REFERENCES

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2. Gas Engineers Handbook, Industrial Press Inc.
3. Fundamentals of Heat and Mass Transfer, Frank Incropera and David Dewitt
4. Burner manufacture product literature
5. Combustion Technology Manual, Industrial Heating Association