DEVELOPMENT OF TECHNOLOGY FOR PRODUCING JAGGERY AND SYRUP FROM SWEET SORGHUM

Submitted to

INDIAN COUNCIL OF AGRICULTURAL
RESEARCH (ICAR), NEW DELHI

NARI
NIMBKAR AGRICULTURAL RESEARCH INSTITUTE,
P.O. Box 44, PHALTAN 415 523 MAHARASHTRA

APRIL 1997

FINAL REPORT OF RESEARCH SCHEME

1. **Project Title :** Development of Technology for Producing Jaggery and Syrup from Sweet Sorghum

2. **Sanction No. :** 4-2/94-AE dated 17/1/1995 (F.No. 3-18/95-G.A.II dated 30/5/95)

3. **Date of start :** 1st April 1995

4. **Date of termination :** 31st March 1997

5. (a) **Name of Institute :** Nimbkar Agricultural Research Institute, Phaltan

   (b) **Division/Department/Section :** Energy

   (c) **Location of work :** Phaltan

6. **Technical Personnel employed :**

Name with Designation	: Date of Joining :	Date of Leaving :	Total No. of man months spent
1. Rajeev M. Jorapur Asst. Director	April 1, 1995	March 31, 1997	24
2. Gasifier operator	May 1, 1995	March 31, 1997	23

7. **Total Outlay :** Rs. 4,34,500 **Share of ICAR :** Rs. 4,34,500

   Share of participating agency : NIL

8. **Total amount spent :** Rs. 4,34,500 **Share of ICAR :** Rs. 4,34,500

   Share of participating agency : NIL

9. **Objectives and how far these have been achieved :** Please see Executive Summary.

10. **Approved Technical Programme :** The program envisages the use of an efficient multi-fuel gasifier furnace system running on loose biomass (like sugarcane leaves, bagasse etc.) for producing Jaggery or syrup. This gasifier furnace system was earlier developed at NARI. An attempt will be made to increase the ease of operation of this system. It also aims to develop an efficient mechanised combustion system for making jaggery, and to compare the efficiencies of the two systems.

    (a) **Remarks of Scientific Panel on earlier Annual Report :** Not received.

11. **Detailed Report** : Please see Chapters I to V.

12 **Summary** : Please see the Executive Summary and Chapter V - Conclusions and Recommendations of this report.

13. **Results which can be exploited in pilot or field scale** : Please refer to the status of the technology in the Executive Summary.

14. **Papers/Articles prepared/published** : NIL.

15. **Suggestions for future lines of research** : Please refer to the recommendations given in the Executive Summary.

16. **Acknowledgements** :

We are grateful to the Indian Council of Agricultural Research (ICAR) for funding this research effort.

We are also extremely grateful to Dr. R. P. Kachru, ADG (Process Engineering), ICAR, New Delhi for his very useful suggestions and comments.

We are also thankful to Dr. Jaswant Singh, Ex-Project Coordinator, PHTS and presently OSD, CIPHET for his extremely useful comments during his visit to Nimbkar Agricultural Research Institute, Phaltan in January 1996.

Thanks are due to our staff members, most notably Shri. S. M. Patil, Shri. D. B. Gadhave, Shri. A. M. Pawar and Shri. D. B. Jadhav for their whole-hearted co-operation.

Finally, we are also thankful to Shri. S. S. Aherrao for his excellent typing and editing skills.

17. **Signature** : AKRajvanshi

Name : Dr. Anil K. Rajvanshi

Designation : Director

Date : 10 April, 1997

Principal Investigator
Director or Incharge
of Institute/Station

LIST OF CONTENTS

Page No.

CHAPTER III : DEVELOPMENT AND TESTING OF SYRUP/GUR MAKING FURNACES

CHAPTER IV : RESULTS AND DISCUSSIONS

CHAPTER V : CONCLUSIONS AND RECOMMENDATIONS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Background

Gur (Jaggery) is an important sweetener used widely in India. The gur industry accounts for over 43 % of the total sugarcane produced in India and has an annual turnover exceeding Rs. 3000 crores. Moreover, it also provides employment to over 2.5 million people in rural areas. Inspite of this, it remains largely unorganized and suffers from a low level of capital, managerial and technological inputs. Thus, it was felt that infusion of modern science and technology into this industry would further increase its relevance and contribution to the Indian economy.

One promising approach towards modernisation of this industry was to develop or identify a suitable alternative to sugarcane for making gur. Sweet sorghum [*Sorghum bicolor* (L).Moench] appeared to be an ideal candidate. It is a four-month crop, requires much less irrigation and fertilizers and is a much more environmentally-friendly crop than sugarcane. Besides providing grain from its earheads, the juice extracted from its stalks contains upto 15% w/w sugars and can be processed to make ethanol, gur or syrup.

NARI had developed the processing technology for making gur or excellent quality syrup from sweet sorghum on a bench-scale plant (13-17 kg/batch of product). So it was decided to scale-up this technology to a pilot scale level (60-70 kg gur or syrup/batch) as the first step towards commercialization of this product. Subsequently, it was envisaged that the existing gur making plants themselves could be used to make the sweet sorghum gur or syrup on a commercial scale.

Thus, it was envisaged that a pilot scale plant (60 - 70 kg syrup or gur per batch) would be set up at NARI. All the production processes would then be stream-lined and the equipments designed to ensure high labour productivity on this scale of operation. Further, there were two options for supplying the necessary heat energy required during the production process - one was to first gasify the bagasse in the low density biomass gasification plant developed earlier at NARI and then to use the producer gas in a furnace; and the second option was to develop a suitable furnace pan system capable of utilizing the bagasse directly from the crusher. Since both these options had certain advantages and disadvantages, it was decided to evaluate both of them in the pilot plant.

Thus, this project was formulated mainly with the objectives of establishing the technology of producing gur or syrup from sweet sorghum on a pilot level scale and to evaluate the use of a biomass gasification system vis-a-vis a suitably designed direct combustion system in this pilot scale plant.

Objectives :

1. To use an efficient multi-fuel gasifier-furnace system developed at NARI and running on loose biomass (like sugarcane leaves, bagasse etc.) for Jaggery-making.
2. To develop an extremely efficient direct mechanised combustion furnace for jaggery-making.
3. To compare the gasifier-furnace system with direct combustion furnace both energywise and economically.

When these objectives were formulated, the major thrust of the research work in this project was intended to be the development of an efficient and mechanised direct combustion system. This system could then be used to produce either gur or syrup from sweet sorghum or sugarcane. However, in the very early stages of the project, it was seen from a limited market survey that syrup from sweet sorghum was preferred to its gur. The sweet sorghum gur was not as sweet and crystalline as sugarcane gur due to its inherently lower sucrose content and higher invert sugar content than sugarcane. Moreover, the sweet sorghum syrup elicited quite a favourable response from consumers, ostensibly due to its perceived therapeutic properties.

It was therefore decided to focus the research efforts on developing the processing technology and the direct combustion furnace for producing excellent quality of syrup rather than gur from sweet sorghum. It was felt that syrup could provide more value addition and better returns to the producer than gur from sweet sorghum. Thus, all the furnaces which were developed and tested in this study were used to prepare syrup and not gur from sweet sorghum. Subsequently, some work was also done to develop a suitable furnace for producing gur from sugarcane.

Methodology of Project Implementation

The project was implemented in the following manner :

(a) As a first step, a suitable furnace-pan configuration was designed and developed for producing 50-70 kg syrup/batch using producer gas generated from the existing commercial scale gasification plant at NARI.

This configuration was then used to stream - line the entire production process and to establish various process parameters like heating and cooling rates, optimum end point temperature and batch time etc. on the pilot plant necessary to produce excellent quality syrup from sweet sorghum.

After the entire process was stream-lined, data were taken regarding the water boiling efficiency of the gasifier-furnace system and the fuel consumption during syrup production from sweet sorghum.

(b) The next step involved the design of a suitable direct combustion furnace based on the data and experience generated during operation of the gasifier powered pilot plant. The design objectives were first clearly spelled out and the developmental work closely followed along those lines.

Three models of the furnaces were developed and tested in the pilot plant. Of these, two were used to make syrup from sweet sorghum. Data were collected regarding their water boiling efficiency and their fuel consumption.

Based on these data, the performances of the different furnace models were compared. The most cost-effective model was then identified.

(c) Some studies were also carried out on gur production from sugarcane, though this was not a part of the original project objectives. Actual data in a commercial scale gur-making plant equipped with a blower and grate attachment was taken. A scaled down version of this furnace was then constructed at NARI and studies pertaining to the water boiling efficiency and fuel consumption during Gur production from sugarcane were carried out.

Thus, the entire work carried out in this project was related to two categories viz. Syrup production from sweet sorghum and gur production from sugarcane. The salient results of each are given below.

Syrup Production from Sweet Sorghum

A pilot scale plant producing 50-70 kg syrup from sweet sorghum was set up during the course of this project. Excellent quality of syrup was produced without using any chemicals. This was mainly due to development of an effective juice filtration system and effective scum removal during the boiling process. It was also found that a rectangular pan was best suited for making sweet sorghum syrup, and so a rectangular pan furnace configuration was designed for this purpose.

This pilot plant was equipped with two sources of heat - one was from the producer gas plant and one was the direct combustion furnace.

Producer gas fired furnace : A producer gas fired rectangular furnace was first designed and tested for its thermal efficiency and its suitability to make syrup. Data during the water boiling tests showed that the overall thermal efficiency was 12.76%, with the gasification efficiency being 50% and the furnace efficiency being 25.5%. This furnace was then used to make syrup from sweet sorghum.

Data showed that the syrup yield was 5.97% by weight of stripped stalks. Further, it was established that to attain fuel self sufficiency during syrup production from sweet sorghum, the fuel consumption had to be less than 4 kg (dry)/kg syrup. However, it was found that the fuel consumption on the gasifier-powered furnace came to 6.26 kg (dry) sugarcane leaves/kg syrup. Thus, fuel self sufficiency could not be attained with this system.

However, operating data and experience generated during operation of the pilot plant on the gasifier-furnace system were used to design a direct combustion furnace. The major design objectives were (a) that the furnace should be able to handle wet bagasse (55% moisture) and (b) that the fuel consumption should not exceed 4 kg (dry)/kg syrup.

Direct combustion system : Initially, it was envisaged that this furnace would be equipped with mechanised fuel handling and ash removing systems. However, this was not found to be a cost effective measure. The increased costs of mechanization could not be offset by reduced labour costs or through increased productivity, and so, this was not incorporated in the final design of the furnace. Thus, both the biomass feeding and ash removing operations were carried out manually in all the furnaces tested in this study.

Three different models of the direct combustion furnaces were designed and tested. The first model featured a separate combustion chamber with ample refractory surfaces to facilitate wet bagasse combustion. A grate with primary and secondary air was also provided. It was found that though this design could sustain wet bagasse combustion, the heat release rate of 540 MJ/h was not sufficient even to boil water. So syrup could not be made using wet fuel on this furnace.

The second model (Model II) also had a grate with primary and secondary air, but it did not have a separate combustion chamber. Instead, it had an extra pan in which bottles used to package the syrup were sterilized in boiling water during the process of making syrup.

This model could sustain combustion of bagasse with an average moisture content of 50% and so one of the major design objectives was successfully met. However, intermittent agitation and poking of the fuel bed were necessary. Moreover, some dry fuel had to be added occasionally to prevent quenching. Some back pressure in the feeding port was also present.

During the water boiling tests, this model gave an overall thermal efficiency of 17-22.7% on sugarcane leaves, with the two pans contributing 13.6-18.2% and 3.4-4.5% respectively. On bagasse, the overall efficiency was 18-20.5%, with the two pans contributing 15.5-17.6% and 2.5-2.8% respectively. Thus, it was seen that use of the additional pan resulted in increasing the furnace efficiency by 2.5-4.5 percentage points.

The fuel consumption during syrup production was 4.62 kg (dry)/kg syrup, which slightly exceeded the target fuel consumption of 4 kg (dry)/kg syrup for fuel self sufficiency. Thus, this furnace was also not self sufficient in its fuel requirements. However, this was because only 2/3 of the pan was used for syrup production, the remaining 1/3 being used to sterilize the bottles. If this was also accounted for, then it was found that the furnace was self sufficient in its fuel requirements.

The third model had features drawn from both the previous models. It had a rear arch extending to about 1/3 of the furnace opening. Besides, it also had two pans like in Model II. This model could also sustain combustion of wet bagasse. Moreoever, the back pressure through the feeding port was considerably reduced as compared to Model II, because the secondary air jets were placed deeper inside the furnace. However, it was slightly more laborious to operate.

Water boiling tests showed that this model had an overall system thermal efficiency of 23.5-25.6%, with the two pans contributing 18.3-20.2% and 5.3-5.4% respectively. Thus, it gave the highest thermal efficiency amongst the three models tested. The fuel consumption during syrup production came to 5.67 kg/kg syrup when it was operated on fuels with an average moisture content of 48.6%. However, this reduced to 4.26 kg/kg syrup when fuel with an average of 40% moisture content was used. This data clearly showed that a trade of is necessary between the moisture content of the fuel used in the furnace and the desired extent of fuel self sufficiency. It was surmised that fuel self sufficiency during syrup production from sweet sorghum could be attained if the furnace was operated on fuels with an average moisture content of 30-40%.

Economic Analysis : An economic analysis for the pilot plant equipped with the direct combustion furnace showed that the equipment cost came to Rs. 1,40,000, mainly because all the vessels were made of stainless steel. However, the cost of the biomass gasification plant itself was Rs. 9,50,000 and so the use of this gasifier for making syrup was not justifiable on economic grounds.

The production cost of sweet sorghum syrup was then calculated by treating the pilot plant like a commercial enterprise. Thus, it was assumed to operate for 300 days per year with one batch operation per day. Equity participation was assumed to be 25% of the project cost and the interest rate on the loan amount was considered to be 20% p.a. on reducing capital. The payback period was assumed to be five years.

This analysis showed that the cost of production of the syrup came to Rs. 27/kg at a sweet sorghum stalk price of Rs. 400/T. After adding all other costs like packing, transportation, advertising and marketing costs, the net price to the retailer was not expected to exceed Rs. 70/kg. Preliminary exposure to the market showed that the syrup could be sold at a retail price of Rs. 80/kg, thereby netting a clear profit of Rs. 10/kg. Thus, it was estimated that this plant itself could achieve an annual turnover of Rs. 14,40,000 and earn a net annual profit of Rs. 1,80,000. Moreover, these can be easily doubled simply by operating the plant for two batches/day.

This promising, though limited, experience showed that the pilot scale plant producing 50-70 kg syrup/batch could itself be an economically viable proposition. This was a significant finding, since it meant that with an investment of Rs. 1,40,000 (excluding land and building costs), an economically viable syrup producing plant could be set up. Further, due to its compactness and manageable logistics, this plant (50-70 kg/batch) has the potential to become the preferred choice of plant size for commercial operations. It is recommended that evaluation of the logistics and other management aspects be undertaken on this pilot plant by operating it over a one-year cycle. This data and experience can then be used to prepare a detailed feasibility study for this plant size. Such an exercise can be attempted in a sequel to this study.

Gur Production from Sugarcane

This study was primarily undertaken to determine the fuel economy of the existing commercial gur-making furnaces and to see if any of the processes developed for syrup production from sweet sorghum could be adapted to gur production from sugarcane.

Consequently, data related to various aspects of the gur-making process were taken on a commercial scale gur making plant in Phaltan area. This was a single pan system processing about 800 kg juice/batch. The furnace was equipped with a blower and grate attachment and was operated on dry fuel only.

The juice extraction in the Vasant # 2 crusher came to 61.9% and the gur recovery was 11.1% by weight of stalks. Further, vigorous combustion of the bagasse was seen in the furnace and the flue gases through the chimney were practically colourless. This was in marked contrast to the black smoke usually seen in commercial gur-making furnaces not equipped with such a blower and grate arrangement.

Further, data showed that about 98 kg (dry) bagasse was generated in one batch, whereas 212 kg (dry) bagasse was consumed. Thus, there was a net deficit of only about 14 kg (dry) bagasse per batch and hence, it was practically self-sufficient in its fuel requirements.

A scaled - down version of this circular furnace was then designed and constructed at NARI. It was found that the efficiency of the commercial scale furnace could not be achieved on the pilot scale furnace. Thus, the maximum efficiency of this furnace was 30% compared to 42% of the commercial - scale furnace. Moreover, the fuel consumption was 2.15 kg (dry)/ kg gur on the smaller furnace, whereas it was only 1.7 kg (dry)/kg gur on the commercial furnace. This clearly showed that further improvements in the furnace efficiency would have to be carried out through experiments on the bigger furnace directly.

However, the elaborate juice filtration system and the production protocol developed for sweet sorghum syrup was found to be extremely useful even for making gur from sugarcane. It was found that excellent quality of gur, both in colour and taste, could be produced in the pilot plant without using any chemicals whatsoever. This was due to the extremely hygienic conditions being maintained in the pilot plant and because all the equipments and vessels which came in contact with the juice were made of stainless steel. This was a very important result, for it clearly showed that addition of indiscriminate quantities of undesirable chemicals like 'hydros' could be avoided by developing a suitable processing technology.

Preliminary market survey showed that this 'chemical-free' gur could fetch a premium price of Rs. 20-30/kg compared to only Rs. 12-15/kg for the best 'Kolhapur' gur. It is therefore suggested that this aspect be further evaluated and the process be adapted to produce 'chemical-free' gur on a commercial scale. This will have a significant impact on the economics of the gur industry.

Some preliminary investigations into making syrup from sugarcane were also made. However, it was found that both floating and settled impurities were present in the sugarcane syrup. Moreover, mold attack and crystal formation were detected after two-three days and seven days respectively. Thus, it was seen that the process used for making sweet sorghum syrup was not suitable for making syrup from sugarcane, and so a different processing technology needs to be developed to produce good quality syrup from sugarcane.

Achievements of the Project

1. A commercially viable pilot-scale plant for producing excellent quality syrup from sweet sorghum or gur from sugarcane has been set up at NARI. About 50-70 kg of the syrup or gur is produced per batch.

2. No chemicals are added at any stage of the manufacturing process. Thus, an absolutely 'natural' product is obtained. This is due to the development of an effective processing technology.

3. A rectangular furnace capable of sustaining combustion of bagasse with an average moisture content of 50 % was developed. It is rated at 1500 MJ/h. All operations like fuel and ash handling are carried out manually in this furnace.

4. Fuel self-sufficiency has been achieved for syrup production from sweet sorghum in the pilot plant. However, this was not possible in case of gur production from sugarcane.

Status of the Technology

Syrup Production from Sweet Sorghum

1. The technology for producing excellent quality syrup from sweet sorghum without adding any synthetic chemicals has been established on a pilot scale level (50-70 kg syrup/batch). It has been shown that this pilot plant itself can be a commercially viable proposition with an estimated annual turnover of Rs. 14,40,000 and a net profit of Rs. 1,80,000 on an initial investment of only Rs. 1,40,000 (excluding land and building costs).

2. About 10% of the syrup produced is affected by a phenomenon labelled as 'frothing', wherein the syrup tends to spill over the bottle when the seal is broken. However, the taste and smell remain unaffected. This aspect needs to be studied further.

3. A rectangular furnace capable of combusting bagasse with an average moisture content of 50% has been developed. This furnace is rated at 1500 MJ/h. The biomass feeding and ash removing operations are carried out manually. It needs to be operated for two hours on dry fuel before wet fuel (50% moisture) is introduced into the furnace. Occasionally some dry fuel has to be added to prevent quenching.

4. It was established that use of a low density biomass gasification system for making syrup or gur was not economically viable, nor did it have any specific advantage over the direct combustion system.

Gur Production from Sugarcane

1. It was found that excellent quality of gur could be produced in the pilot plant without using any chemicals. However, detailed studies like the shelf - life of this 'chemical-free' gur have not been carried out.

2. It was found that use of a wet bagasse combustor for gur production may not be a feasible proposition. For fuel self sufficiency on wet bagasse operation, the required furnace efficiency is 45%. It is felt that this may not be attainable, if major changes in the furnace design and operation are not to be made. Further, wet bagasse combustors typically have a start-up period of six-eight hours. Since the gur-making furnace is typically operated only for 10-12 hours in a day, it is felt that wet bagasse combustors are not suitable for making gur from sugarcane.

3. It was found that use of a blower and grate arrangement in a commercial gur-making furnace resulted in fuel self-sufficiency being attained on dry fuel operation.

Recommendations

1. It is recommended that the pilot scale plant developed in this study be operated throughout the year to produce syrup from sweet sorghum. The phenomenon of frothing seen in some of the syrup bottles can then be investigated. A detailed techno-economic feasibility study of this size of the plant for full-fledged commercial operations can also be carried out. If found feasible, this plant can be made modular in nature, thereby helping to standardize the equipments used in the plant.

2. It was seen that fuel self-sufficiency with fresh (wet) bagasse may not be possible during gur making from sugarcane. If wet bagasse is to be used, extra fuel will be needed which is not a viable proposition. Instead, operation on dry fuel may be a better alternative. It is recommended that this aspect may be investigated further and studies be conducted on commercial gur making furnaces to establish this premise.

3. It is recommended that the processing technology for producing syrup from sugarcane be developed. It is felt that like in case of sweet sorghum, excellent quality syrup may provide more value addition and better returns to the producer than gur in case of sugarcane also.

CHAPTER I

INTRODUCTION

1.1 Background :

Gur (Jaggery) is an important sweetener used widely in India. It competes directly with sugar for the use of sugarcane, which is the common raw material for both the products. Thus, data for 1994-95 reveal that of the total sugarcane produced in India, 44.6% was utilised to make white sugar, ~43.4% was used to make gur and khandsari, and the remaining 12% was used as seed and feed for chewing[1]. However, whereas the sugar industry is highly organised and commands substantial capital, managerial and technological inputs, the gur industry in India remains unorganized and suffers from low levels of these inputs. Till recently, in Maharashtra, the sugarcane growers always first sent their sugarcane to sugar factories due to the higher procurement price of sugarcane paid by them. However, low gur prices and depressed margins did not permit this phenomenon in the gur industry. Only if there was a glut of sugarcane crop which the factory could not absorb, or if the factory was closed down for some reason or other would sugarcane be processed by the farmers to make gur.

But, since recent times, the market price of gur has been increasing at a phenomenal rate to the extent that at times, it even exceeds the white sugar price. This remarkable fact has boosted the growth of the gur industry and increasingly, farmers are now preferring to process the sugarcane crop and market the gur rather than send the crop to the sugar factory. Other factors contributing to this are :

(i) Farmers can get instant cash by selling the gur in the open market. If they sell their cane to the sugar factory, they are paid in installments, sometimes even upto 2-3 years after the sale.

(ii) Due to the labour problem of cane cutters (especially in Maharashtra), quite a large number of farmers cannot get their cane cut in time and hence, get a reduced price because of reduction in cane weight. However, the farmers can process the sugarcane and make gur at the appropriate time.

As a result of this trend, the gur industry has now become a Rs. 3000 crore industry, and plays a crucial role in the rural economy of India[2]. It provides employment to about 2.5 million people in rural areas and has had a tremendous beneficial impact on the socio-cultural milieu of the rural society[2]. This important contribution of the gur industry was highlighted during the "National Seminar-cum-Group Discussion on Jaggery Manufacture and Storage" at the Indian Institute of Sugarcane Research (IISR), Lucknow on December 18-19, 1995[3]. During these deliberations, it was felt that infusion of modern science and technology into the gur industry would further increase its relevance and contribution to the Indian economy.

One attractive approach towards modernisation of the gur industry was to identify or develop a suitable alternative crop to sugarcane for making gur. Sweet sorghum (*Sorghum bicolor (L). Moench*) appeared to be an ideal alternative. It is a multi-purpose crop, which can provide grain from its earheads, and the stalks can be utilised as fodder for animals or to produce a variety of products like ethanol or gur and syrup.

Nimbkar Agricultural Research Institute (NARI) has been working on sweet sorghum breeding and utilisation since 1960s with the twin objectives of (a) developing hybrids/varieties which could yield the maximum amount of grain and sugar and (b) developing suitable products based on the juice extracted from the sweet sorghum stalks [4]. Seeds of the best syrup yielding varieties and hybrids in USA were brought to India and crossed with the best local varieties/hybrids. By 1992, NARI had developed a hybrid which gave yields of 2 T/ha season of fairly good quality grain and which had 10-15% w/w sugars in the juice extracted from its stalks [4].

Two promising product lines derived from the juice were developed. One was to produce ethanol by fermentation of the juice. A pilot plant producing 50 lpd of 95% v/v ethanol was set up at NARI to demonstrate this technology[5]. Another option was to concentrate the juice to produce gur or syrup as is done in conventional gur-making units. Following lab-scale experiments, NARI successfully completed a CAPART sponsored two-year research project entitled "Development and Propagation of Efficient Gur-Making Technology for Rural Areas"[6]. During this project, experiments were conducted mainly with the objective of developing suitable processing techniques to make excellent quality gur or syrup from sweet sorghum. Even after the project ended in 1992, NARI continued its R &D using its own internal funds. It was found that syrup was preferred to gur from sweet sorghum. This was because sweet sorghum gur was not as sweet and crystalline as sugarcane gur due to comparatively lower sucrose content. However, the syrup found ready acceptance amongst users, and so most of the research efforts were then directed towards improving the quality of syrup from sweet sorghum. The major achievements of this research effort are :

a. A new hybrid of sweet sorghum which produces excellent syrup almost throughout the year has been developed.

b. A low density biomass gasifier has been developed and tested for making syrup from sweet sorghum or gur from sugarcane.

c. A complete process for making excellent quality syrup from sweet sorghum has been developed[6]. During this developmental phase, a bench-scale syrup making plant producing 13-17 kg/batch of syrup was set up at NARI. It consisted of a 3-roller crusher powered by a 10 HP electric motor, a settling-cum-filteration system and a circular pan. It was powered by a low density biomass gasifier which was also developed at NARI.

Studies were then conducted on the product quality and the nutritive value of the syrup. Some samples of the syrup were sent to the Central Food Technological Research Institute (CFTRI), Mysore and to a private Govt. - recognised laboratory in Mumbai [7]. The results of their analysis are given in Table 1.1. Data on the constituents of honey are also included in this table for comparison. As can be seen in this table, the syrup is highly nutritious, being rich in vitamins, minerals and proteins. It is also seen that there were no chemical additives like sulphur, benzoic acid, external colouring matter or even pesticide residues.

Table 1.1 : **CONSTITUENTS OF SWEET SORGHUM SYRUP AND HONEY**

	SYRUP [7]	**HONEY** [8] (Average)
Caloric value, Cal/g	2.6	3.26
Total soluble solids, % wt	77.0	81.00
Total Reducing sugars, % wt	70.3	70.4
Protein (N x 6.25), % wt	1.65	--
Ash, % wt	3.69	0.59
	mg/100 g	
Calcium	160.0	5.0
Phosphorus	11.0	4.1
Riboflavin (Vitamin B)	10.0	0.06
Vitamin C	11.5	5.0
Nicotinic Acid	153.0	32.0
Iron	0.86	0.59
Sodium	86.0	4.7
Potassium	1810	90.0
Sulphur	Not detected	8.0
Benzoic acid	Not detected	
Added colouring matter	Not detected	
Pesticide residues	Not detected	

The syrup was then test-marketed to assess its acceptance in the market. Consumer response to this syrup was quite encouraging, mainly for its perceived therapeutic properties if the unsolicited comments received by NARI from regular users is any indication. Some of these are given below :

User's Comments

1. "…. intend to use it as a tonic for the nervous system and as an antacid." … Yoga Dham, Nasik.

2. "… helped me in controlling my asthma" A Mumbai Chemical Engineering Company executive.

3. "Fantastic with light and black tea.. gives instant energy … even helped in controlling weight" -- Mumbai housewife.

4. "….had purchased the syrup and have stopped taking sugar"….. Mumbai Architect.

As a result of this encouraging response, it was decided to initiate the process of commercialization of the syrup. Since the syrup making process was very similar to gur-making, it was envisaged that commercial-scale gur making plants (called 'gurhals' in Marathi) could be used to make sweet sorghum syrup. In Maharashtra, all the gurhals are of the single pan type processing about 800 kg of juice per batch. The then existing bench-scale plant at NARI processed about 60-70 kg juice per batch. This meant that a scale-up factor of about twelve was involved if the bench-scale operation were to be expanded to a commercial scale operation. This was not considered to be advisable.

A more prudent step was to expand the capacity of the bench-scale plant from 60-70 kg juice to a pilot-scale plant processing about 400 kg juice/batch. Subsequent scaling up of the technology from 400 kg/batch to 800 kg/batch would not pose many problems. So it was decided to set up a pilot scale syrup making plant processing about 400 kg juice to produce ~ 60-70 kg syrup/batch.

In addition to developing the processing technology, NARI had considerable experience in working with biomass fuels. Thus, it had developed a full-fledged commercial scale (1080 MJ/h) model of a low density and leafy biomass gasification system[9]. This system was being used to provide the heat for boiling the juice in thebench-scale syrup-making plant. The use of this gasifier had resulted in almost complete elimination of fly-ash in the product, considerable ease of operation of the plant and tight quality control over the product. This gasifier was sufficient to power the proposed pilot scale plant also.

However, another alternative was to develop a direct combustion system for the pilot-scale plant. The main advantage of such a system is that it can accept fuels with higher moisture content than a gasification system and hence is more suited for the syrup making plant. Besides, such direct combustion systems could be more easily scaled-up to fit the conventional commercial scale gurhals.

In these gurhals, the furnaces are of the natural draught type with no grate. The bagasse burns in a pile on the ground with extremely poor distribution of the combustion air in the furnace. This design necessitates the use of absolutely dry bagasse with the moisture content preferably below 10% for effective operation. Freshly crushed bagasse from the crusher typically has ~ 55-60% moisture content, and so it needs to be dried before it can be used in the furnace. Sun drying of bagasse is an extremely laborious and costly affair, besides requiring considerable land area. If the furnace could be slightly modified to accept even partially wet bagasse, it has the potential to effect considerable savings in labour and land cost involved in sun-drying of bagasse.

Thus, this project was formulated mainly to demonstrate the use of a multi-fuel gasifier-furnace system and to develop an improved direct combustion system for making syrup from sweet sorghum on a pilot scale level. The technical and economic viability of these could then be examined.

1.2 Previous Work :

The entire focus of research work in this project was on developing and evaluating two alternative technologies for generating heat for making syrup from sweet sorghum. They were gasification and direct combustion of bagasse or sugarcane leaves.

In 1992, NARI had reported the use of a low density gasifier for making sweet sorghum syrup for the first time[6]. There is no other work reported in the literature on the use of a biomass gasifier for making gur or syrup.

However there were quite a few reports on attempts to improve the furnace for burning bagasse directly. Most of these were related to gur-making furnaces. However, since there was no fundamental difference between making jaggery from sugarcane and syrup from sweet sorghum, it was felt that the developments in the gur-making furnaces could be utilised to develop a suitable furnace for making syrup from sweet sorghum. So, a literature search was carried out to document the research efforts in developing wet or dry bagasse-fired furnaces suitable for making gur.

A 1966 publication of Planning Research and Action Institute (PRAI), Lucknow[10] reported the development of furnaces with thermal efficiencies of 40-43%. These were designed to combust only dry bagasse. All of them were designed for multi-pan systems which are very popular in UP. Thus, the 'Rohilkhand' and 'Standard' bels have five pans, whereas the 'Meerut' and 'Improved Meerut' bels have four pans, including a 'gutter pan'. Due to this, all of them provided a large heating surface to capacity ratio to increase the furnace efficiency (ranging from 4.39 m^2/m^3 capacity in case of Rohilkhand Bel to 7.9 m^2/m^3 in case of the 'standard' Bel)[10].

Further, a design of a furnace capable of combusting wet bagasse directly was attempted by Shri. Jagjit Singh, Chief Fuel Engineer, NSI[11]. It was attached to the 'standard' Bel (with 5 pans). Though this furnace could combust 55% moisture fuel, it required more time and more fuel was consumed per batch (16-17% of stalks on dry weight basis as compared to 12-13% if dry bagasse is used). This was apparently not acceptable. It was subsequently modified and a separate combustion chamber was experimented with. But this needed more draught than the chimney could provide. Moreover, the system had to be operated for more than 8-10 hours before the chamber could sustain wet bagasse combustion. This was felt to be of limited use in commercial practice where the plant is normally operated for only 12-16 hours in a day. This effort was then abandoned.

A heat recovery device and a better recuperator was then designed by Shri. M. K. Garg in 1964-65 to fit into this furnace [11]. It consisted of five oblong welded tubes of 90 cm (3 ft) length and 15 cm (6 in.) width welded into a frame. This frame had two cross-channels at the ends - one for cold air and one for hot air. They were welded at a distance of 30 cm (1 ft) on each tube. Five such frames were joined one upon another. The hot air was taken through a channel in the floor covered by bricks to the combustion chamber. It was discharged in the chamber through an iron plate. This design was reported to work very well on wet bagasse, with both the fuel consumption and the time required for one batch of gur within acceptable limits. The report stated that this furnace design was ready for commercialization in 1966.

This report seemed to be very promising and it was hoped that these results could be duplicated and/or adapted at NARI for single pan systems. This was thought necessary because almost all the gur making plants in Maharashtra are of this type. However, the details of the furnace/combustion chamber design were not given in the report, and all attempts to elicit more information on this technology were not successful [12].

An excellent bibliography on gur and khandsari research in India has been prepared by IISR, Lucknow[13]. Though there are reports of improvement of jaggery-making furnaces by IISR Lucknow[14], operating data could not be obtained. RARS, Annakapalle[15] reported the development of a double grating furnace which reportedly consumed about 35-39% of air dry bagasse or 45% of trash on juice weight basis, i.e. it consumes ~ 35-39 kg of air dry bagasse or 45 kg of sugarcane trash to process 100 kg of juice.

Thus, it is seen that most of the developmental work on gur-making furnaces has focussed on developing natural draught furnaces running on air-dry bagasse and suitable for multi-pan gur-making plants. It was thus thought necessary to launch a research effort and develop an efficient direct combustion system running on wet bagasse and which was suitable for making syrup from sweet sorghum. This furnace could then be adapted and made suitable for producing gur on single pan systems. This latter development would be especially relevant in Maharashtra, where almost all the gur-making plants are of the single-pan type. Thus, the development of such a direct combustion system on a pilot scale is the first step towards improving the economics of these plants.

1.3 Objectives :

The objectives of the project were :

1. To use an efficient multi-fuel gasifier-furnace system running on loose biomass (like sugarcane leaves, bagasse etc.) which has been developed at NARI, for Jaggery-making.
2. To develop an extremely efficient direct mechanised combustion furnace for jaggery-making.
3. To compare the gasifier-furnace system with direct combustion furnace both energywise and economically.

1.4 Scope of the Project Work :

The scope of this project work was to develop a pilot-scale syrup or gur making plant producing about 50 kg of the product per batch. It was envisaged that the existing commercial scale gasifier plant (1080 MJ/h) at NARI would be used to run this pilot scale plant. All the production processes and process parameters were to be streamlined and optimised on this plant.

Data generated on the gasifier powered plant were then to be used to design and develop a direct combustion furnace suitable for making syrup or gur. It was envisaged that this furnace would be completely mechanised and would be the fore-runner of a whole class of rural agro-based industries.

The pilot plant was to be operated on both the biomass gasification plant and the direct combustion furnace. The overall system thermal efficiency and the economics of operating the pilot plant on these two systems were to be compared. This project did not envisage any experiments on commercial scale syrup or gur making plants.

1.5 Methodology of Project Implementation

At the outset, a producer gas fired furnace suitable for producing 50 kg syrup per batch from sweet sorghum was designed and developed. This furnace was then used to operate the pilot plant. All the production processes were stream-lined and some of the equipments redesigned in order to increase labour productivity and the product quality. Process parameters like the heating and cooling rates, juice clarification techniques and the optimum end-point temperature were all finalised. A detailed protocol for producing excellent quality syrup from sweet sorghum was developed, including an activity-time chart for optimum labour productivity. This activity was completed in the first year of the project.

Data obtained from the gasifier-powered pilot plant operation were used to design a direct combustion system. Since a rectangular furnace was found to be best suited for syrup production from sweet sorghum, this furnace was first designed. Initially, the thrust was on developing a wet bagasse combustor which would be capable of combusting bagasse directly from the crusher (at 55 % moisture levels) and at the same time, ensuring fuel self-sufficiency for syrup production from sweet sorghum.

It was envisaged in the proposal that this combustor would be equipped with mechanised fuel and ash handling operations. However this did not turn out to be a cost-effective measure. The increased initial cost of mechanisation was not offset either by reduced labour cost or through increased productivity, and so, mechanisation of the furnace was not incorporated in the final design.

Three different models of the rectangular furnace were then tried out, of which two appeared to be promising. These furnaces were equipped with an extra pan to sterilize the glass bottles which were used to bottle the syrup.

Data were then collected on different aspects of the syrup-making technology. Water boiling tests were conducted on both the gasifer-powered furnace and the direct combustion furnaces. The fuel consumption data were collected during the actual syrup-making process on these furnaces and their thermal efficiencies were compared. An economic analysis was also attempted to determine the most cost-effective choice of the furnace for making syrup from sweet sorghum.

During the last quarter of the project, some experiments were also carried out on gur production from sugarcane even though this activity was not a part of the objectives of the project. Actual operating data on a commercial gur making plant equipped with a blower and grate attachment were collected. A scaled-down version of this furnace was constructed at NARI and this furnace was evaluated for its thermal efficiency.

1.6 Structure of the Report

Chapter II describes the process and equipment designs of the pilot scale plant. Based on the optimum process parameters, a material flow chart for syrup production from sweet sorghum is given in this chapter. The procedures used to design the gasifier powered furnace and the bagasse fired furnace are also described here.

Chapter III details the development of the furnaces used in the manufacture of syrup and gur from sweet sorghum and sugarcane respectively. Various models of the wet bagasse furnaces which were tested during the course of this project are described here. Details of their performances are also included in this chapter.

Chapter IV is essentially a compilation of the results and data presented in Chapter III. It is meant to provide an overview of the important outcomes of this project. It describes the salient features of the pilot scale plant and the performance of the furnaces developed during this project. It also contains the economics of operating these furnaces and of the pilot plant operation.

The final conclusions and recommendations are given in Chapter V.

CHAPTER II

PROCESS AND EQUIPMENT DESIGN

This chapter contains a brief description of the process used to make syrup from sweet sorghum and the different equipments used to set up the pilot scale syrup-making plant at NARI. It also outlines the design methodology used to develop different models of the direct combustion furnace running on wet bagasse and suitable for making syrup from sweet sorghum. Finally, it also describes the methodology used to collect data on gur making from sugarcane in a commercial gur-making plant and to design a scaled-down version of this furnace.

2.1 Process

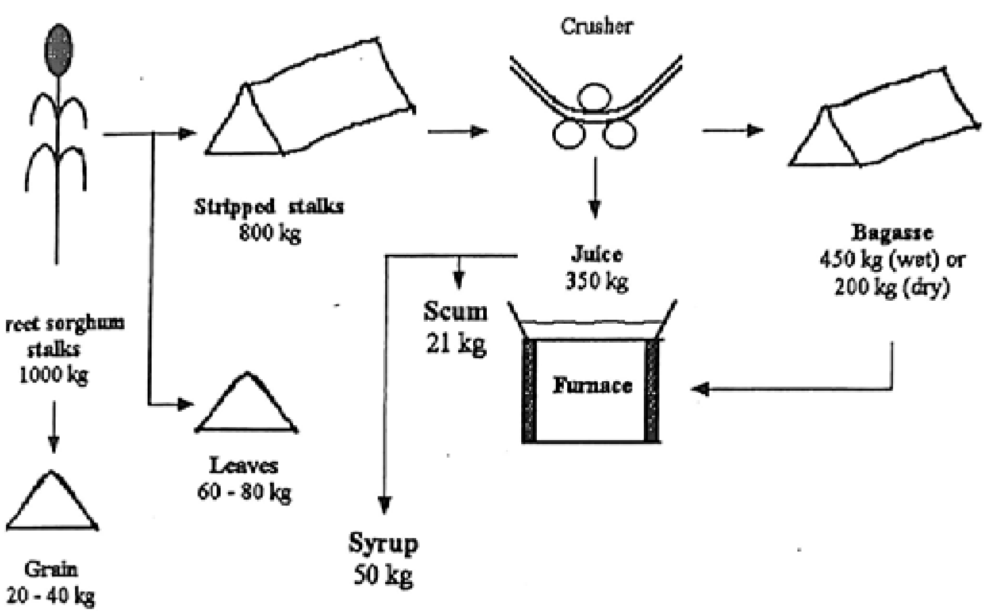
The process developed in an earlier study[6] for making excellent quality of syrup from sweet sorghum was used in the present project. Thus, the sweet sorghum stalks were harvested and stripped manually. Though stripping, which means removing the leaves from the stalks is very labour intensive, it was found essential to ensure good quality syrup. For logistical reasons, the stalks were harvested and stripped one day prior to making syrup. Thus, the stalks were stored for upto 18-20 hours before they were crushed. The juice was then clarified and taken to the boiling pan. Just prior to boiling, all the floating impurities formed as scum were carefully removed. Earlier studies at NARI[6] had conclusively established that the removal of scum from the boiling juice was extremely vital to attain a high degree of clarity in the syrup and to obtain a good texture and crystallinity in jaggery. Besides, there was a marked improvement in taste also if proper and complete scum removal was achieved. So, throughout the boiling process, the scum was continually removed and care was taken to ensure that there was no 'boiling' in of scum due to excessive heating. Boiling was continued till the desired consistency was obtained, depending on whether syrup or gur was being produced. A complete protocol for producing 50-70 kg syrup per batch was developed during this project. The conceptual material flow diagram of producing syrup from sweet sorghum is shown in Fig. 2.1.

2.2 Equipment

Prior to this project, there was a bench-scale syrup-making plant producing 13-17 kg syrup/batch. Four female and three male labourers were required in this plant, and only one batch could be produced per day. Thus, the productivity of human labour was quite low. Besides, the equipments used for handling the juice and filtering it were only utilitarian in nature and were not ergonomically designed. Thus, one of the major expected outcomes of this project was the setting up of an extremely hygienic plant where all the operations and the equipment designs and layout would be geared towards ensuring ease and convenience of operation, and thereby attaining high labour productivity. This was achieved in the pilot scale plant producig 60-70 kg syrup/batch. All the equipments are made of stainless steel, and the juice or syrup/gur does not come into contact with any iron material throughout the manufacturing process. The major equipments of this plant are described below.

2.21 Crusher

A 3-roller crusher (Kirloskar make Sharat No. 2) driven by a 10 HP electric motor was used. This crusher was similar to that generally used for crushing sugarcane, except for the lower clearance between the rollers. This was necessary because of the smaller diameter of the sweet sorghum stalks



Fuel availability : 9 kg (wet) or 4 kg (dry) / kg syrup

Fig. 2.1 : Material flow diagram of producing Syrup from Sweet Sorghum

when compared to sugarcane.

2.22 Juice Clarification System

The clarity of syrup and the quality of gur is dependent to a considerable extent on the effectiveness of the juice clarification system. In the bench-scale plant, the juice was filtered in three stages-first through a coarse filter and was allowed to stand for about two hours. It was then passed through BSS 150 mesh and finally through BSS 200 mesh.

This process was extremely time consuming and laborious, requiring one hour and four female labourers. This operation was made extremely convenient by designing suitably large sized stainless steel mesh filters. The filters were so placed that the juice flows through the stainless steel meshes by gravity and the clarified juice is collected in a tank. This arrangement eliminated the need for gravitational settling, thereby reducing the batch time by two hours. This meant that the juice could be transferred to the boiling pan as soon as the crushing or juice extraction was finished. In case of gur, this is an added advantage since the inversion of sucrose due to storage of juice is thereby prevented. Moreover, juice rejects during filtration was practically eliminated, resulting in increased yields of syrup from sweet sorghum and gur from sugarcane.

2.23 Pan

The design of the pan was primarily influenced by the physical process of efficiently removing the scum when making syrup from sweet sorghum. Careful observation of the boiling juice showed that the pattern of movement of the insoluble particles tended to be from the hot boiling interior to the cooler peripheral walls of the pan.

It was seen that this process of scum removal was best achieved in a pan of rectangular cross section rather than a circular one. Thus, throughout this project, syrup from sweet sorghum was always made on the rectangular pan only. The cross sectional area of the pan was so sized that there would be a minimum of 5 cm (2") thick layer of the product at the end-point when 50-70 kg syrup or jaggery per batch was being made. This was considered essential to prevent any 'scorching' or caramelization of the finished product. Moreover, during the process of boiling, the entire mass expands by more than 50% of its original volume. So sufficient head space was provided in the pan to accomodate this expansion. The sides of the pan were tapered to facilitate scum removal. Thus, the pan measured 80 x 160 cm at the base and 90 x 170 cm at the top with a depth of 45 cm.

Stainless steel was chosen as the material of construction of all the equipments used in the syrup-making plant at NARI. This was to avoid darkening of the syrup or jaggery reportedly due to contact of juice with any equipment made from mild steel[16]. This was also borne out by actual experiments at NARI.

2.24 Rectangular Furnace

The design of the furnace, especially its cross-section, is primarily influenced by the geometry of the pan and the fuel which is to be used. Thus, a rectangular furnace was designed for the rectangular pan. There were three options with regard to the fuel which was to be used. One was to use producer gas, the second one was to use mill-wet bagasse and and the third was to use dry sugarcane leaves or bagasse as is the common practice in commercial gur-making plants. The design details of these are described below.

2.241 Gas-fired furnace

NARI had developed a commercial scale model of a low density and leafy biomass gasification system with a rated thermal capacity of 1080 MJ/h (300 kW thermal)[9]. The specifications of this system are given in Table 2.1.

Table 2.1 : TECHNICAL SPECIFICATIONS OF THE NARI GASIFICATION SYSTEM [9]

1. Capacity	1080 MJ/h (2,58,000 Kcal/h)
2. Biomass consumption	100-125 kg/h (dry)
3. Char production	20-30 kg/h
4. Gas calorific value	3.55-4.81 MJ/Nm^3
5. Gas flow rate	225 Nm^3/h
6. Gasification efficiency	
(a) Without considering char	50 %
(b) Considering char	78 %

This system generated producer gas from fuels like sugarcane leaves, bagasse, sweet sorghum stalks and bagasse, bajra residues etc. The gas, which has a calorific value of 3.55 - 4.81 MJ/Nm^3, can be burnt in suitably designed burners to give flame temperatures exceeding 1000°C. It was proposed to use this gas for making syrup, as it was thought that the gasifier-furnace combination could result in increase in efficiency over the existing furnaces. It also offered a greater degree of control over the heating rate as compared to a solid-fired furnace. Moreover, the extent of fly-ash in a gas-fired furnace is almost negligible when compared to that in a solids fired furnace. All these factors pointed to production of a superior quality of syrup/jaggery on a gas-fired furnace, and so, a gasifier-powered furnace was designed.

A gas-fired furnace is fairly simple in construction, since there are no moving parts (like stokers or ash handling equipments etc.). Moreover, the producer gas flame length is only about 60 cm, so a long combustion chamber is not necessary. The gas flow rate was estimated from the fact that 279 kg of water needed to be boiled of to produce 50 kg syrup (Refer to Fig. 2.1). Since the batch time was around four hours, the boiling rate came to approximately 70 kg/h of steam. Assuming a very conservative furnace efficiency of 20%, about 900 MJ/h of heat was needed to be supplied to the furnace. Since theaverage gas calorific value was ~ 4.18 MJ/Nm^3, the expected gas flow rate came to ~ 215 Nm^3/h. Thus, the existing gasification system with a rated gas flow-rate of 215 Nm^3/h was suitable for this scale of operation. At an air/fuel ratio of one, the combustion air flow rate was also 215 Nm^3/h.

The cross section of the furnace was dictated by the pan geometry. Thus, since the pan bottom was 80 x 150 cm, the furnace opening was kept at 70 x 140 cm. This allowed an overlap of 5 cm for the pan bottom to rest on the furnace construction. A gas-fired furnace can be extremely compact. However, in the event of any failure in the producer gas plant when the syrup/jaggery was being made, there was the danger of an entire batch going waste. Thus, it was thought prudent to have a provision for burning other fuels like wood, dry bagasse or sugarcane leaves at least to complete the process. So, even though a furnace height of 1 m was sufficient for gas operation, an additional 0.5 m height was provided in the combustion chamber. This extra volume was to facilitate solid-fuel operation and for ash hold-up for about four hours. A baffle wall was also provided half-way along the length of the furnace to reduce fly-ash emissions. It should be noted that this furnace was primarily meant to operate on producer gas, and so, no efforts were made to increase its efficiency on solid fuel operation.

The internal details of the furnace are seen in Fig. 2.2. High temperature refractory bricks were used for the inner lining of the combustion chamber. Ordinary bricks were used for the outer layer and for the rest of the furnace. The wall thickness was kept at 23 cm (9 in.). The flue gas duct was sized to have a maximum velocity of 5 m/s. The chimney was constructed of bricks upto the level of the gas outlet duct and thereafter was fabricated using mild steel. The chimney diameter was 1 ft and the net height was 10 ft (above the gas outlet duct). Inspection doors were provided in the combustion chamber to permit visual observation of the producer gas flame.

No grate was provided. Instead, a refractory hearth was constructed and provision was made to pump in primary air in case solid fuel was used. The producer gas burner was embedded in the wall and was 50 cm above the hearth. In case of solid fuel operation, secondary air was pumped in through this burner. The feeding port for solids was above the gas burner. Sufficient volume was provided in the furnace so that it could be operated for four-five hours on sugarcane leaves without any ash removal. On bagasse or wood, it could be operated for an even longer time.

The furnace was well instrumented with K-type thermocouples in the combustion zone, the middle zone and at the base of the chimney. Air flow rates were measured using a caliberated orifice meter and/or an anemometer. The hot gas flow rate was monitored using an orifice-meter. The biomass consumption rate was estimated by actually weighing the biomass being consumed in the gasifier. A 200 kg steel-yard balance with a least count of 100 g was used for this purpose.

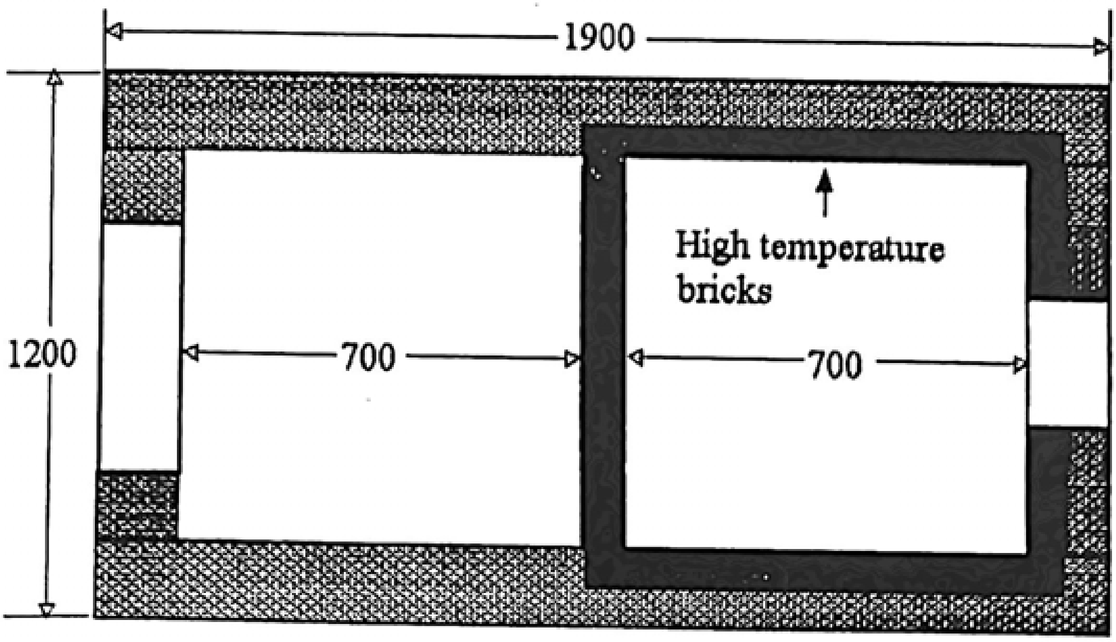
After the furnace was constructed, the producer gas piping was modified so that the gas could be directly burnt in the furnace. With this, the gasifier-powered syrup making plant was ready for testing. This is seen in Fig. 2.3. Initially, during the commissioning, water boiling tests were carried out to ensure that the chimney provided sufficient draught to overcome the furnace pressure drop and to ensure good combustion. Subsequently, the furnace was used to make syrup from sweet sorghum. The results of the performance tests of the gasifier-furnace system are given in Section 3.11.

2.242 Wet Bagasse Furnace Design

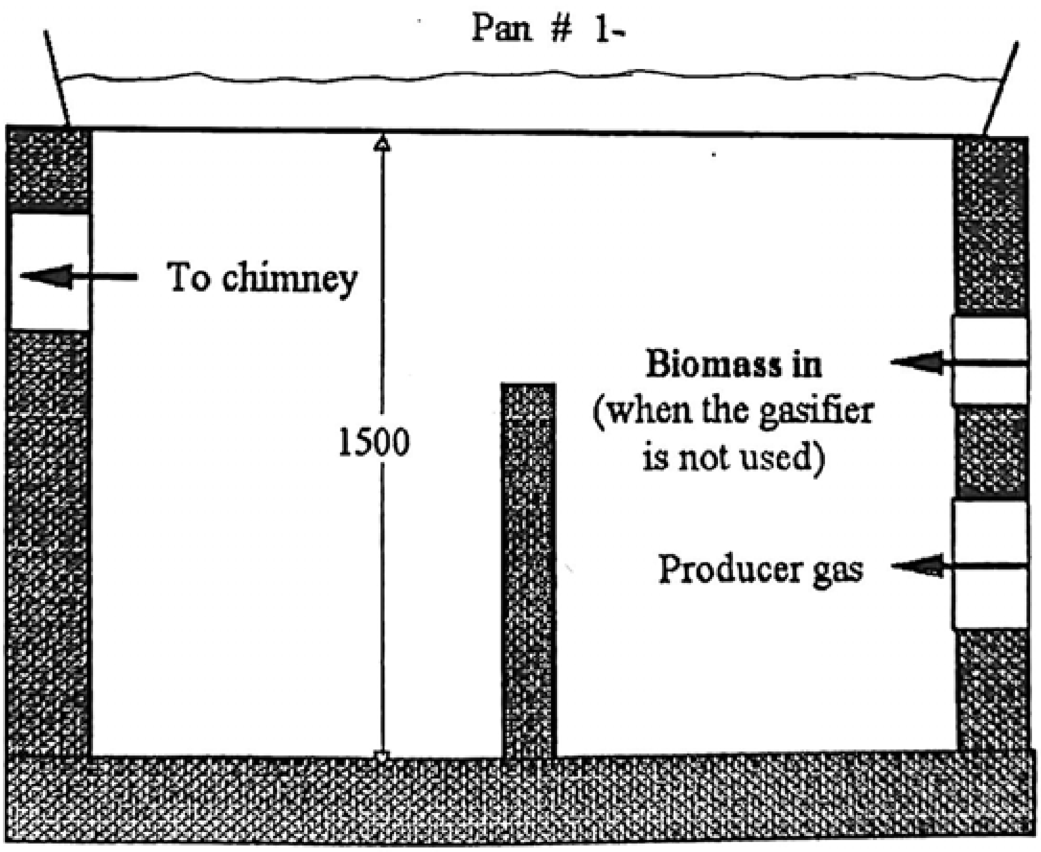
Since the gasifier powered syrup making furnace had a rectangular pan, it was decided to design a wet bagasse combustor for the same pan. This would enable direct comparison between the gasifier-powered furnace and the direct combustion furnace.

At the outset, important parameters like the expected biomass consumption rate and air flow rates were estimated. Several alternative furnace configurations were considered based on available literature and data generated internally at NARI. The most promising configuration was then chosen. The size of grate and the furnace volume were calculated and the chimney was designed using the norms available in literature. The details of these are given below :

1. **Expected biomass consumption rate :** One of the primary requirements of the furnace was that it should be self-sufficient in its fuel requirement, i.e. the bagasse generated from the sweet sorghum stalks should be sufficient to produce syrup from the juice obtained from these stalks. The pilot scale plant was to be sized to produce 60 kg syrup/batch of 4 hours. From the material flow sheet given in Fig. 2.1, it is seen that about 9 kg wet (with 55% moisture) bagasse is available to produce 1 kg of syrup. Thus, to produce 60 kg syrup, about 540 kg (wet) bagasse would be available. Since



Sectional View of Plan



Sectional View of Elevation

All dimensions in mm

Fig. 2.2 : Internal Details of gas - fired furnace

Commercial-scale Low Density Biomass Gasification Plant (1080 MJ/h)

Gasifier-powered Syrup-making Furnace

Fig. 2.3 : Gasifier-powered Syrup-making Plant

the batch time was 4 hours, the expected biomass consumption rate was 135 kg/h (wet). For design purposes, this was taken to be 150 kg/h (at 55% moisture content). Since the gross calorific value of dry sweet sorghum bagasse is 18 MJ/kg, the required furnace heat release rate came to 1215 MJ/h.

The required thermal efficiency of the furnace to achieve fuel self-sufficiency was then estimated. However, it should be noted that when wet fuel is being used, a significant portion of the heat energy of the fuel is used up in evaporating the water contained in the fuel. To account for this unavoidable loss of energy, the thermal efficiency of the furnace on wet bagasse operation is calculated on basis of the net and not the gross calorific value of the fuel. For sweet sorghum bagasse with 55 % moisture, the net calorific value came to 6.74 MJ/kg (wet) or 14.97 MJ/kg (dry). From Fig. 2.1, it is seen that about 279 kg water was required to be removed, whereas 450 kg (wet) bagasse was available for this purpose. Thus, the required thermal efficiency of the furnace based on the net calorific value of sweet sorghum bagasse came to 24 %.

In terms of dry bagasse utilisation, about 200 kg (dry) bagasse was available to remove 279 kg water and produce 50 kg syrup. The target furnace efficiency in this case (based on the gross calorific value of dry sweet sorghum bagasse) came to 20 %.

This exercise clearly showed that a higher furnace efficiency of 24 % was required for wet bagasse operation as compared to 20 % for dry bagasse operation. This was because extra energy is required to evaporate the water contained in the wet fuel, and hence, this energy is not available for the process.

2. **Air flow rate :** This was derived from the expected biomass flow rate and the ultimate analysis of sweet sorghum bagasse and sugarcane leaves which are given in Table 2.2 [17]. Simple stoichiometric calculations showed that the theoretical air requirement for complete combustion of sweet sorghum bagasse was 4.8 kg/kg bagasse (dry). Thus, for a biomass consumption rate of 150 kg/h (55% moisture) or 70 kg/h (dry), the theoretical air flow rate for complete combustion was 337 kg/h.

   Since the amount of excess air for efficient combustion could not be ascertained *a priori*, provision was made to vary the excess air from 0 to 200 %. Gopala Rao et al.[18] reported that the optimum excess air for combustion of wet bagasse (50% moisture) was 38%, so an excess air of 50% was assumed for estimating the required air flow rate. Thus, the actual air flow rate was estimated at ~7.2 kg/kg bagasse (dry). For a bagasse consumption rate of 70 kg/h (dry), the air flow rate came to ~ 504 kg/h.

   The next step was to design suitable air inlet manifolds. This was influenced to a great extent by the high volatile content of bagasse (~ 75% w/w). Therefore, it was surmised that most of the combustion will take place above the grate and only the fixed carbon will combust on the grate. Thus, it was felt that at least two different ports of entry of air in the furnace need to be provided - one through the grate (primary air) and one in the combustion space above the grate (secondary air). It was felt that the primary air will contribute mainly to combustion of fixed carbon on the grate whereas the secondary air will be responsible for combustion of the volatiles above the grate. This meant that the ratio of primary to secondary air had to be nearly similar to that of fixed carbon to volatiles. In case of sweet sorghum bagasse, this ratio was 1:3.77 and so it was decided to design the air inlets for primary and secondary air to follow the same ratio. The primary and secondary air flow rates were therefore estimated at 104 kg/h and 400 kg/h respectively, assuming about 50% excess air is used.

Table 2.2 : PROXIMATE AND ULTIMATE ANALYSIS OF SWEET SORGHUM BAGASSE AND SUGARCANE LEAVES[17]

	Sweet sorghum bagasse	Sugarcane leaves
A. Proximate Analysis		
	% w/w (dry)	% w/w (dry)
1. Fixed Carbon	20.09	14.88
2. Volatile matter	75.75	77.4
3. Ash content	4.16	7.2
B. Ultimate Analysis		
1. Carbon	44.08	39.75
2. Hydrogen	5.26	5.50
3. Nitrogen	-	0.186
4. Oxygen	46.50	46.84
5. Ash	4.16	7.72
6. Higher heating value,		
MJ/kg (dry)	18	17.38
kWh/kg (dry)	5.03	4.84

Since the primary air was to be sent through the grate, care had to be taken to minimize the char/ash carryover. Therefore, the velocity of the primary air was kept below 3 m/s. In case of secondary air, the air jet had to penetrate the flame, which meant that high velocities were required. Available literature[19] recommended a minimum velocity of 20 m/s for effective flame penetration. Thus, the secondary air manifold was designed to inject air at velocities exceeding 20 m/s.

Once these basic parameters were established, the next step was to choose the best furnace configuration amongst several available alternatives. One of the earliest designs of a furnace for combusting wet bagasse was that of the Cook's furnace[20]. It was characterised by having ample high temperature refractory areas needed to burn fixed carbon and the volatile matter of bagasse. The hearth was typically 1.2-1.67 m (4 ft -5 ft 6 inch) wide and 1.8-2.13 m (6 ft -7 ft) long. The height of the furnace was ~ 3-4.3 m (10 ft -14 ft). The fuel was burnt in a pile in large quantities on a refractory hearth. In this design, air impinged on the pile surface and there was no grate, ostensibly due to the slagging nature of bagasse. The maximum combustion rate was ~ 1720 kg dry bagasse/h.m^2 of hearth area with the economical furnace loading being ~ 1000 kg/h.m^2. Subsequent improvements led to inclusion of a rear arch to improve ignition of the wet fuel. Another design was the sloping grate design wherein bagasse was fed on an inclined grate and air was fed through the grate and the bridge wall[20, 21]. Yet another option was the spreader furnace where the bagasse was projected into the furnace volume by a drum-type rotary feeder[20, 22]. The bagasse was widely dispersed inside the furnace and most of the combustion air was through the grate.

The literature search thus showed that wet bagasse furnaces were developed and commercially established mainly for very large capacities. There were no reports of any established designs of small-scale furnaces. Besides, the engineering parameters for these large furnaces could not be utilised in the designs of small furnaces.

Concurrent to this literature search, a market survey was also launched to identify any vendors of small-scale wet bagasse furnaces. Correspondence was initiated with manufacturers of solid fuel boilers, furnaces and other solids fired thermal experiments[23 - 30]. It was found that the existing furnaces catered to the extremely powdery form of bagasse available in the sugar factories. Thus, the furnaces/boilers were equipped with fuel handling equipment and combustion chamber designs suitable either for the loose or for baled bagasse. However, they were not suitable for the type of long, unchopped bagasse generated from the 3-roller crusher used in the syrup making plant (and also in the commercial gur-making plants). Chopping this bagasse into smaller sized particles and then using them in these furnaces entailed a level of investment not commensurate with the syrup making activity.

It was therefore surmised that the existing designs were not suitable for the syrup making plant or even for the commercial scale gur-making plants in Maharashtra. This meant that the design of the furnace would have to be developed from the basics and from the documented experience of operating the large capacity furnaces. The sequence of this developmental work was (a) Fuel and Ash handling equipment, (b) Combustion chamber design, (c) Air distribution in furnace and (d) Chimney design. These are detailed below :

(a) **Fuel and Ash Handling Equipment :** The availability of appropriate and cost-effective fuel and ash handling equipment influences the design of the furnace to a considerable extent. In the manually operated furnaces, continuous feeding of bagasse is necessary and the labourer engaged in this task has virtually no time to rest when the furnace is being operated. Thus, the fuel feeding operation is extremely laborious, and it was to reduce this drudgery that mechanisation of this activity was conceived of in this project.

Previous experience [9, 31] on different designs of solids handling equipment at NARI proved relevant here. This had resulted in the development of a scraper drag-out conveyor for the gasification plant (seen in Fig. 2.3) [9]. This conveyor was designed to handle dry biomass like sugarcane leaves and bagasse and to hold biomass sufficient for about 30-45 minutes of operation, after which it could be again loaded by one person in 10-15 minutes. Thus, one labourer was engaged for only 10-15 minutes for every 40-60 minutes of the gasifier plant operation. This scheme, if implemented for the syrup making furnace, had the potential to meet one of the major purposes of mechanisation, which was to reduce the drudgery of manually feeding the biomass. Thus, the design of this scraper drag-out conveyor was sought to be adapted to make it suitable for the syrup-making furnace.

However, the design of a mechanised feeding system is primarily influenced by the physical properties of the material to be handled. In case of sweet sorghum, the bagasse from the 3-roller crusher was 1-1.25 m (3 ft - 4 ft) long and was fibrous in nature. It did not shear into smaller pieces even after drying and it was extremely difficult to handle such long particle sized biomass fuels in the conveyor. A better option was to chop the bagasse into smaller particles and then to use a suitable conveyor (either screw-type or a scraper drag-out type) to feed the bagasse to the furnace. However, the chaff cutter was not designed to handle wet biomass, which meant that it also had to be modified for this purpose.

Moreover, the hopper design for handling bagasse was also tricky. Bagasse tended to adhere to each other and formed a 'bridge' inside the hopper, thereby disrupting the flow of biomass from the hopper into the conveyor. For wet fuels, this problem was even more prevalent. Thus, this operation had to be carried out manually, which meant that one person was required to load the conveyor at all times.

Though these problems could have been rectified and the necessary design changes incorporated in the equipments, it was felt that the substantial investment required for mechanisation of the fuel handling system could not be offset by reduced labour cost, since only one labourer was required in either case (manual feeding as well as using a conveyor). Thus, though mechanisation of fuel feeding operation was envisaged in the proposal, this did not turn out to be a cost-effective measure, and so, was not incorporated in the final design of the furnace. It is felt that even for the existing scale of commercial gur-making operations in Maharashtra (~ 750 l/batch), manual feeding of bagasse still remains the most cost-effective solution.

The same factors were also relevant for the ash handling equipment. Thus, it was decided to have only manual fuel and ash handling operations for the syrup making furnace.

(b) **Combustion chamber design :** This is the heart of the furnace, and its design includes the design of the grate, the combustion volume to be provided and the geometry of the chamber. For efficient heat release during combustion, a certain minimum grate area and combustion volume are required. The grate area and the furnace volume need to be matched to design a furnace of a given output. If the furnace volume is too small in relation to the grate, then, combustion will not be completed in the furnace and there will be unburnt constituents in the stack gases. If the grate area is very small, then the required heat release rate may not be maintained.

This problem is especially accentuated when the combustion of wet bagasse is involved. During combustion, the free moisture in the bagasse absorbs heat by evaporation of the liquid water and heating of the resulting water vapour. This lowers the amount of useful heat available from the fuel and also decreases the combustion temperatures. Thus, the design of the combustion chamber needs to take this factor into account. The effect of moisture content on combustion chamber design for boilers fired with fibrous fuels is given in Table 2.3[32].

Table 2.3 : EFFECT OF MOISTURE CONTENT ON COMBUSTION CHAMBER DESIGN FOR BOILERS FIRED WITH FIBROUS FUELS [32]

Moisture content range	Preferred combustion chamber and heat recovery combination	Comments
Greater than 56%	Refractory lined	Combustion unstable. Predrying required. This can be done either internally as in a Hearth furnace or by means of an externally located predrying system.
50% to 56%	Partly water cooled with air Pre-heater. Undergrate air temperature of at least 200^{0}C required at 56% moisture content	Combustion relatively stable. Some refractory is required in furnace to improve combustion stability.
40% to 50%	Partly water cooled with air pre-heater or economizer OR Fully water cooled with air pre-heater	Combustion stable. Unlikely for slag to form in partly water-cooled furnace. In fully water-cooled furnace an air pre-heater is advisable to improve combustion stability.
30% to 40%	Fully water cooled with economizer	Combustion stable with tendency for slag to form.
Less than 30%	Fully water cooled with economizer	Combustion stable. Strong tendency for slag to form, particularly with fuels having high alkali metal content.

It is thus seen that to sustain combustion of 55% moisture fuels, undergrate air temperature of at least 200^{0}C is recommended. Moreover, some refractory is also required in the combustion chamber to improve the stability. These factors were taken into account during the design of the grate and the combustion chamber, the details of which are given below :

(i) **Grate design** : Most of the development work on grate designs pertain to coal combustion. Coal in India typically has 50 % fixed carbon and 30 % volatiles [33], so most of the combustion takes place on the grate. Hence the grate design becomes extremely important for coal combustion. However, biomass has only 20 % fixed carbon, whereas its volatiles content is 75 % (Refer Table 2.2). So, in this case, most of the combustion takes place above the grate and only the fixed carbon component combusts on the grate. Thus, it appeared that the grate design may not have as great an impact on the furnace performance as in coal. In fact, in some furnace designs, the grate is dispensed with altogether due to the slagging nature of bagasse [20]. A refractory hearth is provided and the bagasse burns in a pile on this surface.

One of the simplest grates is the horizontal grate consisting of a cast-iron grid onto which the fuel is fired. Primary air is fed under the grate and secondary air is fed in the combustion volume over the grate. Besides, unlike in other designs like the travelling grate or spreader stoker [20,22], there were no moving parts in this design. This afforded both the simplicity of design and the advantage of low first cost, and so it was decided to evaluate this grate design for combustion of wet bagasse.

The grate design basically involves estimating the grate area required to sustain a given heat release rate. The required grate area was calculated from the grate heat release rates reported in literature [34]. Since the grate and volumetric heat release rates are closely linked, estimates of both these parameters reported by different authors are compiled in Table 2.4 [34].

Table 2.4 : GRATE AND VOLUMETRIC HEAT RELEASE RATES IN DIFFERENT FURNACES

Reference	Grate heat release rate (kW/m^2)	Volumetric heat release rate (kW/m^3)
Breag et al., (1986)		210-280
Tillman et al., (1981) pile burning	2360	
Livingston et al., (1990)	800-850	
Trinks and Mawhinney, (1951)		
poor mixing		60
fair mixing		220
Tillman, (1987)		
inclined grate	970	140
wet cell	1560	210
spreader stoker	2830	140-210
ETSU, (1990)		

From the data relevant to grate-fired systems, a slightly conservative grate heat release rate of 700 kW/m^2 was chosen for wet bagasse combustion. Since wet bagasse (with 55% moisture content) has a gross calorific value of 2.3 kWh/kg (Refer Table 2.2) and the expected biomass consumption rate was 150 kg/h, the required grate heat release rate came to 345 kW. This meant that the grate area had to be 0.49 m^2. Since the width of the rectangular pan was 80 cm, a square grate with dimensions of 70 cm x 70 cm was considered to be the most appropriate size.

At a biomass consumption rate of 150 kg/h (wet), the grate loading came to 306 $kg/h.m^2$ of grate area. This was also in good agreement with the typical boiler design norms of 200-500 kg (dry)/$h.m^2$ for wet bagasse combustion [18], and agreed well with the recommended specific load of 75-150 $kg/h.m^2$ for small municipal solid waste incinerators[35]. The next step was to choose an appropriate material of construction of the grate. Since the primary air had to be fed from below the grate, it was decided to fabricate the grate using 3.81 cm (1 ½ in.) diameter pipes to form a grid like structure. Air would flow through these pipes and would then be discharged through suitable openings facing downwards (towards the furnace floor). This arrangement offered the twin advantages of (a) keeping the grate cool due to the air flow and (b) causing the primary air to be preheated before it came into contact with the wet biomass. This was in line with the suggested requirement that undergrate air needs to be preheated to at least 200^{0}C to sustain wet bagasse combustion (Refer Table 2.3).

The velocity of air through the grate was designed to be in the range of 1-3 m/s in order to minimize char carryover into the stack gases. Further, a scraper was also provided on the grate to displace ash from above the grate to the ash pit located below the grate. This was to be operated manually, thereby helping to control the height of the char bed in the furnace.

(ii) **Combustion volume** : The cross-section of the furnace was dictated largely by the pan dimensions. Thus, a rectangular cross section of 70 x 140 cm was chosen as it was suitable for the pan whose dimensions were 80 x 150 cm. This provided an overlap of 5 cm on each side on which the pan could be kept. The combustion volume then depended solely on the height of the furnace. The height of a solid combustion zone was related to the grate area A by the following correlation [35]:

$$H = 1.3\, A^{0.36}$$

Where H = Height of combustion chamber, m
A = Grate area, m

Though this correlation was used for combustion of municipal solids waste with moisture contents of 30-70 %, it provided a first estimate of the height required for combustion of bagasse. For a grate area of 0.49 m^2, the minimum height required came to 1 m.

Further, from Table 2.4, assuming an average volumetric heat release rate of 210 kW/m^3 of furnace volume, the required volume for a heat release rate of 345 kW came to 1.643 m^3. For a furnace with cross sectional area of 0.98 m^2 (0.7 x 1.4 m), the required height of the furnace came to 1.677 m. Since this was greater than the earlier estimate of 1 m, the furnace dimensions were fixed at 0.70 x 1.4 x 1.75 m high.

(c) **Air Distribution** : The primary and secondary air flow rates were estimated at 104 kg/h and 400 kg/h respectively (Refer Section 2.242). The primary air flowed through the pipes which constituted the grate. The discharge ports were pointed towards the furnace floor and were designed to have a velocity of 1-3 m/s.

For the secondary air distributor, the main requirements were (i) to provide sufficient air for combustion of the volatiles released from biomass, and (ii) to create vigorous turbulence in the chamber and ensure proper mixing of the volatiles and the combustion air.

The secondary air was fed above the grate in the combustion chamber. It was realized that the key issue to obtain high combustion efficiency was to ensure proper mixing of the air and the volatiles. This meant that the air was required to penetrate the flame, and so, the air jets were designed to have velocities exceeding 20 m/s. It was expected that, mixing being a physical phenomenon, different manifold designs would need to be evaluated experimentally to arrive at the most suitable configuration of the secondary air distribution. So two configurations were designed and tested.

In the first model, the air jets were placed directly in the path of the flue gases. The jets were directed opposite to the flow of the gases and it was expected that this model would provide excellent mixing of the air and the flue gases. However, there was a possibility that the back pressure created by this excellent turbulence would result in some flue gases or even the flame reaching the feeding port. This was not acceptable since there would be a likelihood of the biomass catching fire in the feeding port itself.

In case the above phenomenon was observed, there had to be an alternative design. In the second model, air jets were to be placed all round the grate in the combustion chamber. This meant that the volatiles released from the biomass would be penetrated by air jets from all sides. It was thought that this configuration would also ensure complete mixing of air and volatiles, and at the same time, result in lesser pressure drop as compared to the previous model. The position of the plane of these jets above the grate was to be established through actual experiments.

(d) **Chimney design :** The major purpose of the chimney is to provide the necessary draught across the furnace to overcome (a) the pressure drop due to the furnace walls and construction and (b) to evacuate the flue gases at the required rate from the furnace chamber. Published literature[10] suggested that a draught of 0.43 cm (0.17 in.) of water column (WC) was sufficient for wet bagasse combustion for commercial scale operation. For the pilot plant scale, the chimney was designed to provide a draught of about 0.4 cm (0.15 in.) WC. Use was made of the procedure outlined in literature[36, 37]. The main factors influencing the chimney design are (a) the temperature of the flue gas at the base of the chimney, (b) the expected temperature drop in the chimney, which again depends on the length and the material of construction of the chimney and (iii) the expected the gas flow rate.

The chimney was designed for a flue gas temperature of 400°C at the base and for a temperature drop of 50°C over the length of the chimney. The chimney was to be made of mild steel initially, since this was more amenable for changes/modifications and could be easily fabricated. The design process showed that a mild steel chimney of base diameter 45 cm (1 ½ ft) and length 5.5 m (18 ft) would be sufficient to provide the necessary draught of 0.4 cm WC in the furnace.

With this, all the basic components of the furnace were designed. Construction of the furnace was then undertaken by the Institute's staff. This enabled tight supervision and on-site changes could be effected more easily. The first model of the furnace was completed in June 1996. Extensive experiments were carried out on this model to (a) ascertain whether it could sustain ~ 50% wet biomass combustion and (b) evaluate its thermal efficiency. Changes and modifications in the internal details of the furnace were carried out as suggested by the experimental evidence and experience obtained during the actual furnace operation. Each design of the furnace was subjected to the following three levels of testing.

(a) **First level :** Here, the primary objective was to test whether wet biomass (50% moisture) combustion could be sustained or not. The furnace was initially operated on dry fuel for about 2 hours and then, the wet fuel was introduced slowly. If it was found that combustion could not be sustained for any significant length of time on wet fuel, the test was abandoned. The design was then changed/modified. However if it was established that combustion could be sustained by addition of ~ 10-20% weight of dry fuel, the result was considered positive and the second and third level tests were then conducted on this design.

(b) **Second level :** This was carried out only if wet biomass combustion could be sustained. Here, the thermal efficiency of the furnace was estimated by carrying out water boiling tests. These were typically conducted for a period of four-six hours. The furnace was subjected to a cold start (i.e. the entire furnace was at room temperature when the tests were started). Dry fuel was used initially for 1 ½ - 2 hours and then the wet fuel was slowly introduced. The water was brought to boil and then the amount of water boiled of vis-a-vis the biomass consumed was monitored when the furnace was operating solely on the wet fuel. These data were used to estimate the thermal efficiency of the furnace.

This test was also used to determine whether the furnace was suitable to make syrup from sweet sorghum. The major requirement was that the water boiling rate had to be at least 60 kg/h so that about 50-60 kg syrup or jaggery could be made in five hours. If the water boiling rate was less than 60 kg/h, then, the furnace was deemed to be unacceptable for making syrup.

(c) **Third level :** This was the final test which established whether the furnace was indeed suitable for making syrup from sweet sorghum. The furnace was deemed to be acceptable if (i) excellent quality syrup could be produced on this furnace, i.e. effective scum removal and good control over the heating rate were possible on this furnace; and (ii) fuel self sufficiency was attained. This meant that the bagasse available from the sweet sorghum stalks was sufficient to make syrup from the same number of stalks.

This testing methodology resulted in quite a few designs being eliminated at the first level of testing itself. Some designs were found wanting at the second level, and finally only two designs were used to make syrup from sweet sorghum. The sequence of development of this furnace design is detailed in Section 3.12 in the next chapter.

2.25 Circular Furnace Design

When the project was conceived, the major objective was to develop an efficient direct combustion furnace for making syrup from sweet sorghum. Accordingly, most of the research work was focussed on this aspect. Since a rectangular pan was found to be best suited for making syrup from sweet sorghum, the entire furnace developmental work was geared towards developing a rectangular furnace.

However, in the last quarter of the project, it was felt that the experience gained in designing and operating a wet biomass furnace could be utilised to attempt to increase the thermal efficiency of existing circular gur-making furnaces. In order to evaluate the feasibility of this concept, it was decided to study the operation of a typical commercial gur making plant with specific reference to the furnace performance. This would yield data on the existing status of the fuel economy of the furnace. Based on this data, a feasible research program could then be chalked out.

Accordingly, a local progressive gur manufacturer [38] was contacted and he evinced a keen interest in this venture. He was shown different models of the rectangular furnace which were being tested at NARI. He was impressed by the fact that practically no smoke was visible when the rectangular furnaces were being operated on dry fuel. Further, the excellent combustion in these furnaces convinced him of the advantages of an additional blower and grate arrangement.

Of his own accord, he introduced such an arrangement in his circular furnace. As is typical in Maharashtra, this was a single-pan furnace with an internal diameter of 2.64 m and height of 1 m. The chimney, which provided the necessary draught through the furnace, was about 4.5 m tall. It was thus a natural-draught furnace. The pan diameter was 2.74 m at the base and 2.97 m at the top with a vertical height of 0.47 m. About 780 kg of juice was processed per batch. The grate consisted of a perforated mild steel sheet with 1.25 cm (1/2") diameter holes through which air from a 1.75 HP blower was blown in the furnace. He reported excellent results with this arrangement, which are given in Section 3.21.

It was then decided to monitor the fuel consumption on site during the actual gur-making operation. Accordingly, a 200 kg steelyard type platform balance was taken to the gur-making plant. Data regarding the amount of sugarcane crushed, the bagasse generated, the juice extracted, the bagasse consumed in the furnace and the amount of gur produced were monitored. In order to allow the furnace to approach steady-state conditions, the data were collected during the fourth batch of the day, i.e. the furnace was in operation for about ten hours before these data were taken. These results are given in Section 3.21.

It was seen that the furnace was practically self-sufficient in its fuel requirements, and so, the gur manufacturer was averse to any changes in his plant layout to further increase the furnace efficiency. However, the possibility of utilizing the wet bagasse from the crusher without drying it appealed to him tremendously, since this would reduce his labour cost significantly. But he emphasized that fuel self-sufficiency was most important. If this could be achieved on wet bagasse, that would be ideal, but otherwise, he preferred to use dry bagasse and have fuel self sufficiency rather than use wet bagasse but be forced to bring in extra fuel.

Since the development of a wet bagasse combustor involved extensive experimentation, it was not practical to carry out this work at his site. So it was logical to consider carrying out this work at NARI itself by constructing a separate circular pan-furnace system. For logistical reasons, it was not possible to operate directly on the commercial scale size of the plant (780-800 kg/batch of juice). A scaled-down version of the circular furnace was then proposed to be constructed at NARI. It was to be sized to produce 50-70 kg gur/batch so as to match the wet biomass and gasifier-powered furnaces described earlier in Section 2.242. This would enable direct comparison between the different furnace designs.

The sizing of the pan was dictated by the requirement that at least a 2.5 cm thick layer of liquid should remain at the end-point to prevent caramelisation of gur. Since the gur yield is about 20% on juice weight basis, the pan had to accomodate about 350 kg of juice per batch. Allowing about 100% of its volume for expansion during frothing, the pan capacity was designed to be ~ 700 kg. The pan dimensions were then fixed at 1.4 m base diameter, 1.5 m top diameter and 0.45 m high. It was to be fabricated from stainless steel.

The design of the circular furnace was then undertaken. The target fuel consumption of this furnace to attain self sufficiency in the bagasse requirements was first estimated. This required information on the average juice extraction, bagasse generated and the amount of water required to be boiled of. Data on these aspects for sugarcane were compiled from different sources and are presented below in Table 2.5.

Table 2.5 : DATA ON GUR PRODUCTION FROM SUGARCANE

1. Juice extraction[39, 40]	60-65 % by weight of stalks
2. Bagasse generated[41]	35% of cane (fresh weight basis)
3. Moisture content of fresh bagasse[41]	40-50%
4. Gur[42]	10-14% on stalk weight basis
5. Gross calorific value of bagasse[10, 17]	18.6 MJ/kg (dry)

Using these norms, data regarding different aspects of processing 350 kg of sugarcane juice per batch to produce gur was prepared. This is given below in Table 2.6.

Table 2.6 : GUR PRODUCTION DATA FOR PILOT SCALE OPERATION

1. Sugarcane, kg	560
2. Juice extracted, kg	350 (62.5% on stalk weight)
3. Moisture content of fresh bagasse	50 %
4. Bagasse generated, kg (wet)	210
kg (dry)	105
5. Gur, kg (10 % on cane weight)	56
6. Water removed, kg	294

It is thus seen from Table 2.6 that about 210 kg (wet) or 105 kg (dry) bagasse was available to produce 56 kg gur. Thus, the bagasse consumption target was 3.75 kg (wet) or 1.88 kg (dry) /kg gur. The required furnace efficiency for wet bagasse operation (based on the net calorific value of bagasse) then came to 45 %, whereas for dry bagasse operation, it came to 38.7 %.

This is a considerably more stringent requirement than was the case of sweet sorghum syrup, where the required thermal efficiency was only 24 % and 20 % for wet and dry bagasse operation respectively. This significant difference was due to the fact that in sweet sorghum, dry bagasse constitutes about 26 % by weight of the stalks, whereas in sugarcane, it constitutes only about 15 - 16 %. Thus, for the same weight of stalks, about 70 % more bagasse is available in sweet sorghum than in sugarcane to process the juice obtained from those stalks.

This exercise clearly showed that the circular furnace had to be considerably more efficient than the rectangular furnace in order to attain fuel self-sufficiency during gur making from sugarcane. This was especially true for wet bagasse operation, for which the required efficiency was 45 % . However, due to temporal constraints, it was not considered possible to embark on such a developmental venture at that stage of the project. So a prudent decision was taken, and it was decided to attempt to increase the furnace efficiency to the extent possible on dry bagasse operation only. Further, no major modifications in the basic design of the furnace were to be attempted. The major thrust was to obtain better efficiency by achieving better mixing of air and the solid fuel.

Accordingly, the design of the circular furnace was then undertaken. Since about 105 kg of bagasse were available and a batch time of 2.5 hours was assumed, the expected bagasse consumption rate came to 42 kg/h. For design purposes, this was taken to be 50 kg (dry)/h. This corresponded to a furnace heat release rate of 930 MJ/h (225 kW). The stoichiometric air flow rate for complete combustion was estimated to be 240 kg/h. Assuming 50% excess air, the expected air flow rate came to 360 kg/h.

The volume of the furnace and the grate size were then estimated. The volumetric heat release rate was assumed to be 210 kW/m^3 (refer Section 2.242), and so the required combustion volume came to ~ 1.07 m^3. Since the pan had a base diameter of 1.4 m, the furnace diameter was fixed at 1.3 m, so that there was an overlap of 5 cm on all sides on which the pan could rest. The height of the combustion chamber then came to 0.80 m. So a height of 1 m was chosen for the furnace.

The size of the grate was calculated by assuming a burning rate of 520 kg/h.m^2 for dry bagasse [10] . The required grate size for 50 kg/h bagasse consumption then came to ~ 0.096 m^2. For design purposes, this was taken to be 0.1 m^2 and so a grate of 40 x 25 cm was then chosen.

Experience with the wet bagasse combustor designs had shown that the furnace walls do not begin contributing to the combustion process untill after six hours of operation. So it was decided to use only ordinary bricks for this furnace, since it was primarily meant for operation on dry fuel only.

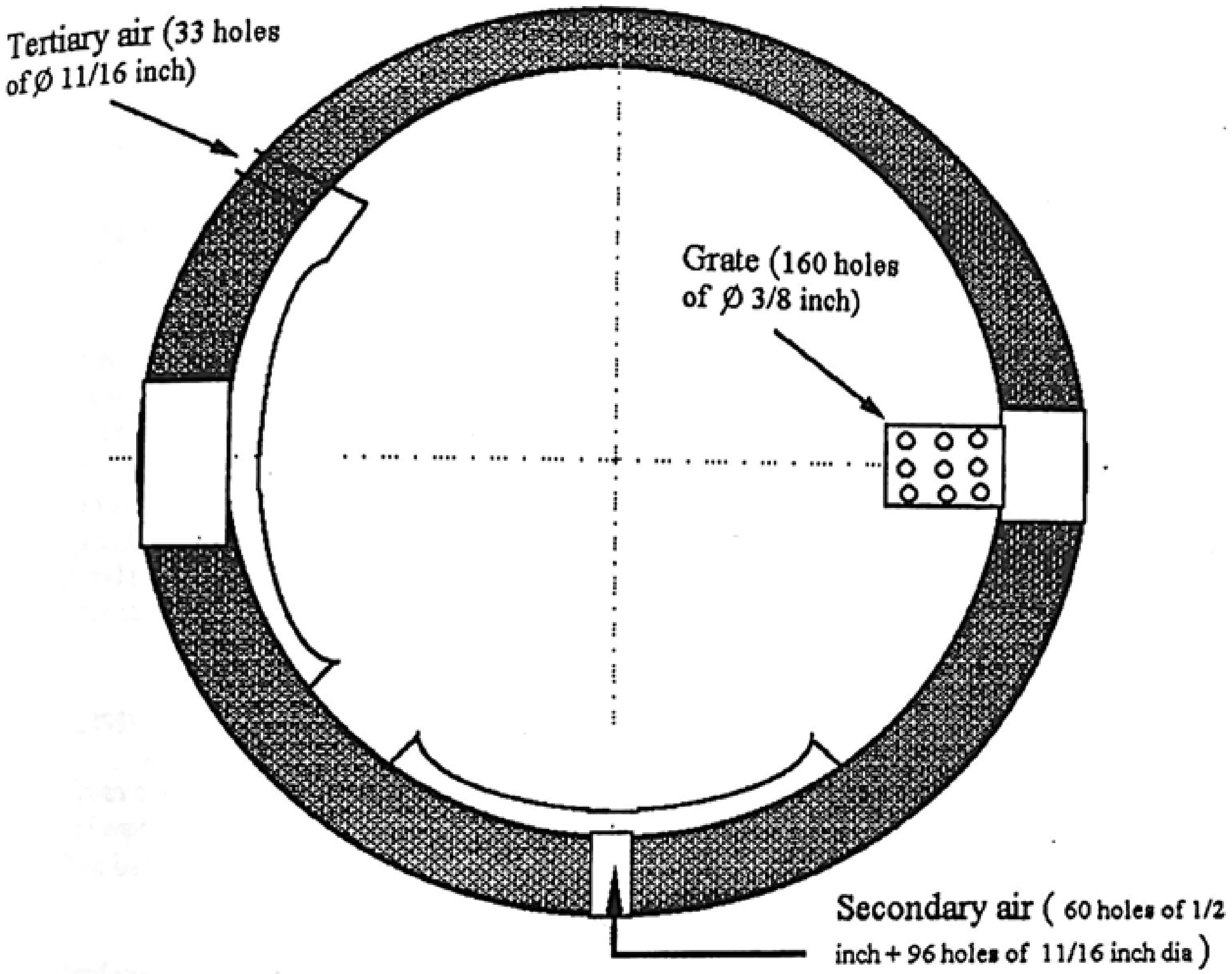
Thus, a circular furnace of internal dimensions of 1.3 m diameter and 1 m height was constructed at NARI. The feeding port was so located that the biomass fell directly on the grate as is seen in Fig. 2.4. A separate chimney made of bricks was constructed for this furnace.

Initially, two inlet ports-one for primary and one for secondary air-were designed. Subsequently, a tertiary air inlet manifold was also added. Provision was made to vary the air flow rates from 0-100% of the total air supplied to the furnace. During commissioning, the optimum locations of the secondary and tertiary air inlet manifolds with respect to the grate and the chimney were determined through experimentation.

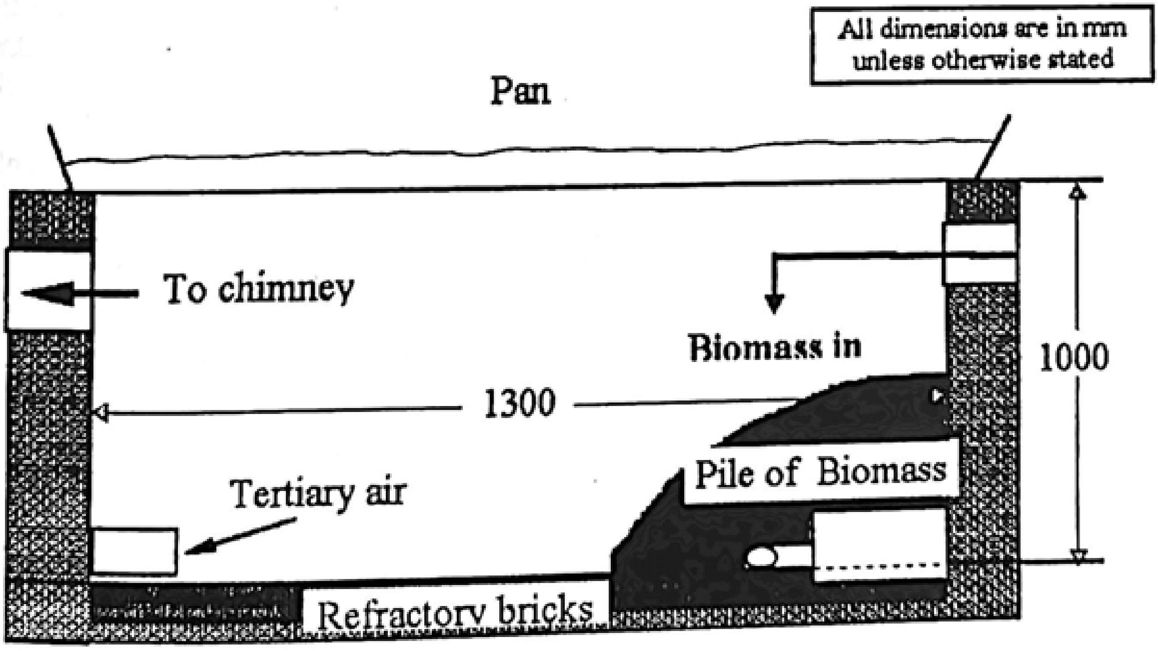
In the first version, the secondary air inlet manifold was kept directly above the grate and below the feeding port. There was no tertiary air. In this model, the high velocity secondary air jets tended to blow the dry sugarcane leaves with considerable force against the opposite wall directly below the flue gas outlet. There was practically no combustion on the grate, since the biomass was not allowed to fall on the grate at all. Further, considerable amount of fly-ash was observed in the chimney. However, the effect of secondary air was clearly discernable. The maximum thermal efficiency obtained during the water boiling tests with dry sugarcane leaves (8% moisture) after two hours of operation was 22%.

The position of the secondary air inlet manifold was then changed to that shown in Fig. 2.4. This caused a dramatic change in the quality of the combustion process. Excellent turbulence was observed, and a swirling flame was created inside the furnace. There was no smoke visible in the flue gases through the chimney. Greyish-white char ash was obtained, indicating a high degree of carbon conversion. However, it was observed that the length of the flame extended to nearly the furnace diameter. In order to shorten the flame length, tertiary air was introduced in the furnace. This reduced the flame length to about 50-60 cm. This arrangement of the secondary and tertiary air inlet manifolds was considered satisfactory.

The next stage was to evaluate the thermal efficiency and to evaluate the fuel economy of the furnace during gur making from sugarcane. Water boiling tests were conducted and gur from sugarcane was made on this furnace. The results are presented in Section 3.22.



Sectional View of Plan



Sectional View of Elevation

Fig. 2.4 : Pilot scale Gur-making Furnace at NARI

CHAPTER III

DEVELOPMENT AND TESTING OF SYRUP/GUR MAKING FURNACES

During this project, two types of furnaces were developed - a rectangular furnace to produce syrup from sweet sorghum and a circular furnace to produce gur from sugarcane. In each case, the furnace was first made operational and preliminary first level tests as described in Section 2.242 were conducted. Water boiling tests were then carried out and after satisfactory results were obtained during these tests, the furnace was used to make syrup or gur. This chapter describes the process of development of these furnaces and the results of their performance tests pertaining to the quality of the product and the thermal efficiency. The syrup making rectangular furnace is first described, followed by the gur making circular furnace.

3.1 Syrup making Rectangular Furnace

Syrup from sweet sorghum was made in a rectangular pan using a gasifier powered furnace and two models of wet bagasse direct fired furnaces. The development and performance of these furnaces are described below.

3.11 Performance of the Gasifier-powered Rectangular Furnace

In this furnace, producer gas from the low density biomass gasification plant was combusted. Thus, this was essentially a gas-fired furnace. The results of the water boiling tests on this furnace are given in Table 3.1.

Table 3.1 :WATER BOILING TESTS ON THE GASIFIER-FURNACE SYSTEM

1.	Fuel used	Sugarcane leaves
2.	Fuel consumption	75 kg/h (dry)
3.	Moisture content	10%
4.	Water boiling rate	70 kg/h
5.	Temperature	
	(a) Combustion zone	700-850 °C
	(b) Base of chimney	470-550 °C
6.	Overall system efficiency	12.76 %

The salient features of its performance were as follows :

(a) It was found that the desired boiling rate of water (~ 70 kg/h) was easily reached. Thus, this system was suitable to make syrup or gur.

(b) The overall thermal efficiency of the system came to 12.76 %. Since the gasification efficiency (without considering char) is ~ 50 % (Refer Table 2.1), the furnace efficiency was estimated at 25.5%. This appears to be on the lower side, mainly because these tests were carried out when the furnace was 'cold'. So most of the heat is utilised in heating the cold furnace walls, and this results in low efficiency in the initial stages. Calculations showed that the furnace could be expected to reach a fair degree of thermal equilibrium after about six-seven hours of operation. Thus, the data presented in Table 3.1 is on the conservative side, especially that related to the thermal efficiency. As the furnace becomes hot, the efficiency is bound to increase. However, data were not collected on this aspect, since these tests were meant only to assess the suitability of the system for making gur or syrup. Actual fuel consumption data was to be collected when syrup or gur was being made.

The gasifier powered furnace was thus found to be satisfactory for making syrup or gur. Consequently, data related to making syrup from sweet sorghum were collected. The results of a typical batch are given in Table 3.2.

Table 3.2 : SYRUP PRODUCTION DATA ON THE GASIFIER-FURNACE SYSTEM

Basis : One batch

1. Whole stalks	1406 kg
2. Stripped stalks	1000 kg
3. Syrup produced	59.7 kg
4. Juice	342 kg
5. Juice rejects	12.6 kg
6. Scum	30.8 kg
7. Water removed	238.9 kg (4 kg/kg syrup)
8. Time required	3.75 hours
9. Producer gas flow rate	175 Nm^3/h
10. Fuel used	Sugarcane leaves
11. Moisture content of fuel used	15 %
12. Fuel consumption	373.5 kg (dry)
13. Specific Fuel consumption	6.26 kg (dry)/kg syrup
14. Temperature at base of chimney	625 °C
13. Furnace efficiency	20
14. Overall system efficiency (without considering char)	10 %

The following were the salient features of syrup production on the gasifier-furnace system :

1. It was seen that the required producer gas flow rate of 175 Nm^3/h was less than expected, which was 215 Nm^3/h (Refer section 2.241). This was mainly because the juice tended to spill over the sides of the pan if the heating rate was increased beyond this limit.

2. The effect of controlled heating on the extent of scum removal was clearly seen during this set of experiments. When fairly vigorous boiling was maintained almost throughout the process, 'boiling in' of scum occured to a significant extent. This resulted in a cloudy appearance to the syrup and the clarity and taste were not good. This occured usually when the batch time was ~ 2.5 hours. However, when slow heating was employed and the batch time extended to 4-5 hours, the quality of the syrup improved dramatically. Scum % removal was very effective and a clear and transparent syrup with an excellent taste was obtained in these batches. Thus, the optimum batch time for producing excellent syrup was revised from the earlier recommended 2.5 - 3 hours[43] to

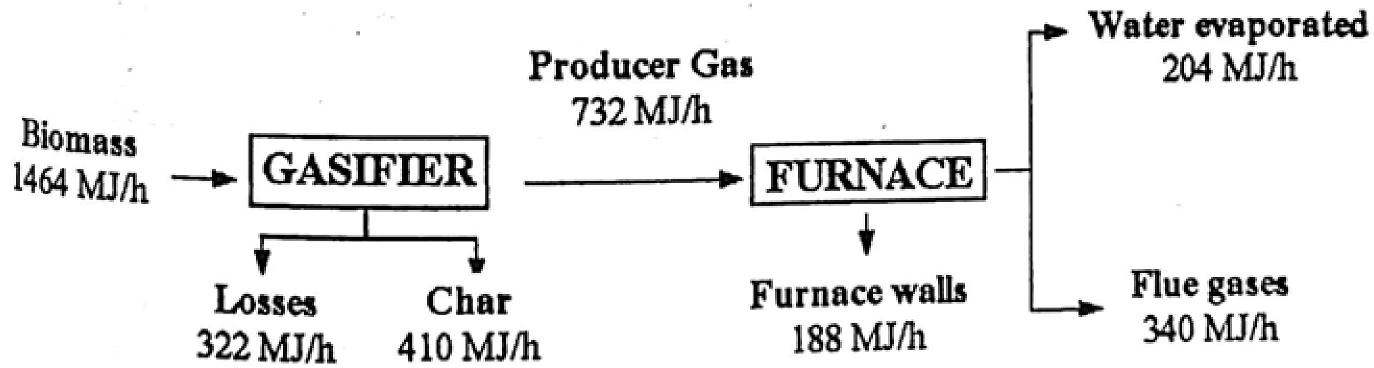
4 - 5 hours.

3. During the early stages of experimentation, four female and three male labourers were required in the syrup producing plant. This was in addition to two male labourers for operating the gasification plant. This was mainly due to inappropriate physical layout of the plant leading to inefficient material handling procedures. However, continued operation of this plant resulted in rearrangement of the physical layout and redesigning of some components of the pilot plant. This increased the convenience of operation and resulted in stream-lining the entire material handling operations to such an extent that the labour requirement for the syrup plant was reduced to three male and two female labourers per shift of eight hours. This resulted in increased productivity and reduced the labour cost.

4. Data on the fuel economy of the gasifier-furnace system, however was not encouraging. Table 3.2 shows that the fuel consumption is 6.26 kg fuel (dry)/kg syrup corresponding to an overall system efficiency of only 10 %. (The earlier estimates of 3-3.5 kg fuel (dry)/kg syrup [40] were based on a batch time of 2.5-3 hours, which is no longer valid). It is seen from Fig. 2.1 that to achieve fuel self-sufficiency, the target fuel consumption was 4 kg fuel (dry)/kg syrup and the required system efficiency was 20 % on dry fuel operation. Thus, the gasifier furnace system was not sufficient in its fuel requirements.

   It is to be noted, however, that since only one batch of syrup could be made every day, the fuel consumption data were generated when the furnace was 'cold'. Thus, a significant portion of the thermal energy supplied to the furnace was utilised in heating the furnace walls. Thus, the present fuel requirement of 6.26 kg (dry)/kg syrup is a conservative estimate. It is expected that if the furnace were to be operated for two-three sucessive batches, the fuel consumption could be reduced significantly.

   A theoretical exercise was therefore attempted to estimate the efficiency of the furnace during steady state operation by assuming the normative values for the furnace losses through the stack and the furnace walls. This was estimated from the heat flow diagram generated during a typical water boiling test for the gas-fired furnace which is seen in Fig. 3.1.



It is seen from Fig. 3.1 that there were two major sources of heat loss in the furnace, viz. Through the flue gases and through the furnace walls. The flue gases were leaving the furnace enclosure at 625 °C, thereby accounting for over 46 % of the input heat to the furnace. It was felt that this loss could be reduced by increasing the contact area between the pan bottom and the flue gases and by introducing an additional pan in the path of the flue gases. This pan could be utilised to sterilize the bottles used to bottle the syrup. It was estimated that the temperature of the flue gases in this case could be brought down to ~ 450^0C without the use of any elaborate heat recovery devices. This would reduce the heat losses to ~ 241 MJ/h, which was about 33% of the input heat to the furnace.

The heat loss through the furnace walls were expected to be reduced during successive batches. Assuming that 5% of the input heat is lost through the furnace walls under steady-state conditions [44] and another 5% is lost due to incomplete combustion and as miscellaneous losses [45], the total furnace losses could conceivably be reduced as shown below :

Source of heat loss	% of input heat to furnace
a. Stack gases exiting furnace at 450^0C	33
b. Furnace walls	5
c. Uncombusted gases, soot etc.	5
TOTAL LOSSES	43

Thus, the furnace efficiency under steady state operation could be expected to reach 57 % and the combined (overall) efficiency of the gasifier-furnace system to 28.6 %. This is the maximum efficiency which can be expected from the gasifier-furnace system (without considering the char produced in the gasifier).

Thus, these studies provided the following important information for optimizing the operation of the pilot plant for producing syrup from sweet sorghum :

(a) It was found that an extra pan could be placed in the path of the flue gases to increase the furnace efficiency. This pan could be used to sterilize the glass bottles used to package the syrup. Thus, the bottles could be dipped in boiling water in the extra pan for a suitable period in accordance with relevant norms. This obviated the need to have any alternative arrangement to sterilize the bottles.

(b) It was established that a batch time of four-five hours was best suited to produce excellent syrup.

(c) All the material handling operations could be stream-lined and the equipments rearranged to obtain high labour productivity and ease of operation.

The next step was to develop a suitable direct combustion furnace operating on wet bagasse to ensure fuel sufficiency for syrup production from sweet sorghum. The results of this developmental efforts are described in the following sections.

3.12 Wet Bagasse Combustor

The development of the wet bagasse combustor was influenced by the following descending order of priorities :

(a) The first priority was to sustain the combustion of wet (~ 55 % moisture) fuels in the furnace, regardless of other parameters like the heat release rate, the start up time required and the thermal efficiency. It was thought that such combustors were suitable for applications extending beyond that of the syrup or gur making plants. They could be used in agro-based industries to utilise the in-house biomass wastes generated by them and produce steam for their own use. Thus, the ability of the furnace to sustain wet biomass combustion was accorded the highest priority.

(b) The next priority was to obtain suitable heat release rates and thermal efficiencies for producing good quality syrup or gur from sweet sorghum and sugarcane respectively.

Different models of the furnace were tested accordingly. The sequence of this developmental work is briefly outlined below :

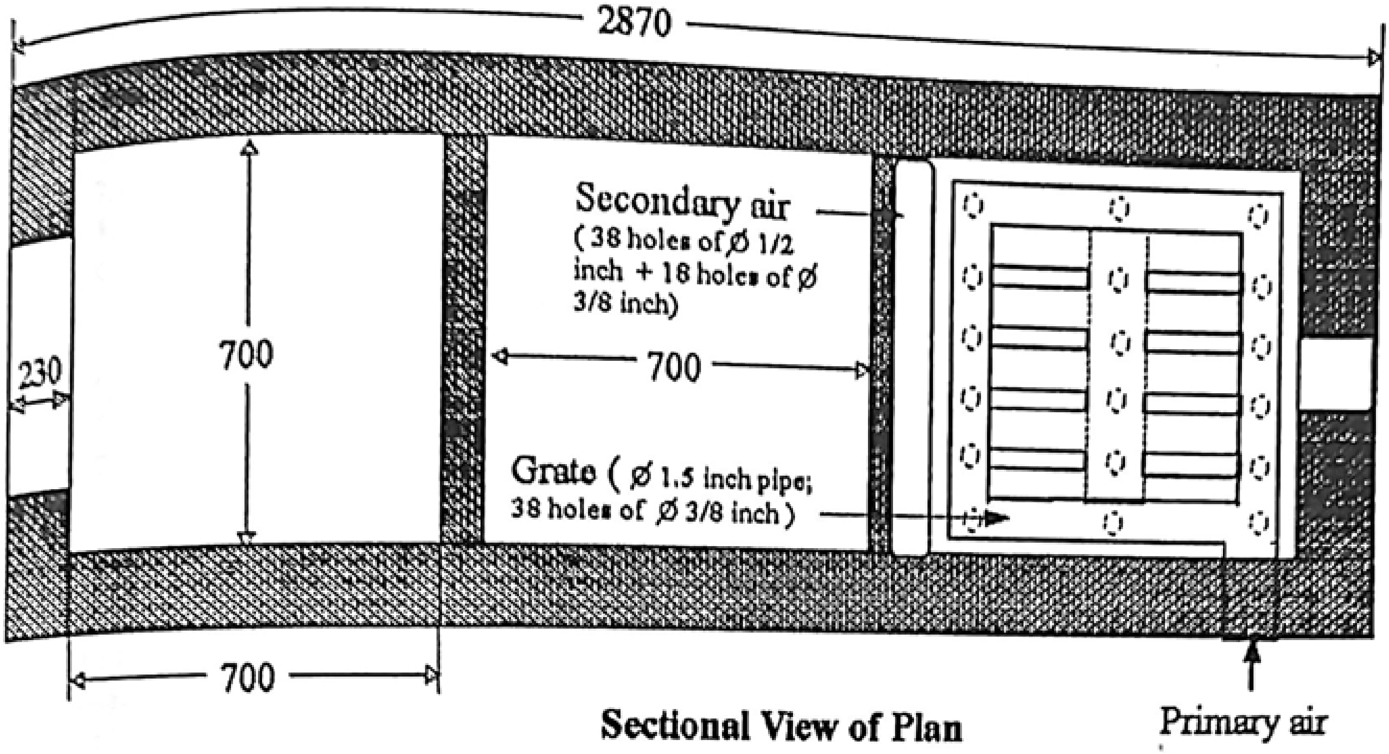
(i) **Model I :** This model seen in Fig. 3.2 had a separate combustion chamber of 70 x 70 cm cross-sectional area and had a height of 1.5 m above the grate. The grate, of size 70 x 70 cm, was kept at a height of 25 cm above the floor of the combustion chamber. It was made of 3.81 cm (1.5 in.) diameter pipes through which primary air was passed. The discharge ports of the primary air were directed towards the floor in such a manner that all the air had to pass through the grate. The secondary air jets were placed directly in the path of the flue gases as seen in Fig. 3.2.

The feeding port was near the roof of the combustion chamber. Thus, a tall pile of biomass was envisaged on the grate, with a 30 - 45 cm (1 ft - 1 ½ ft) thick bed of glowing charcoal. It was thought that the radiative energy from the hot combustion chamber walls and the glowing charcoal bed and the convective energy from the hot flue gases as it flowed through the pile of biomass would be sufficient to dry the wet biomass (with ~ 55% moisture) and cause it to ignite. The parameters of interest were (i) the start-up time required for the combustion chamber to heat up and start radiating sufficient energy to dry the wet biomass and (ii) the temperature of the flue gas as it exited the combustion chamber.

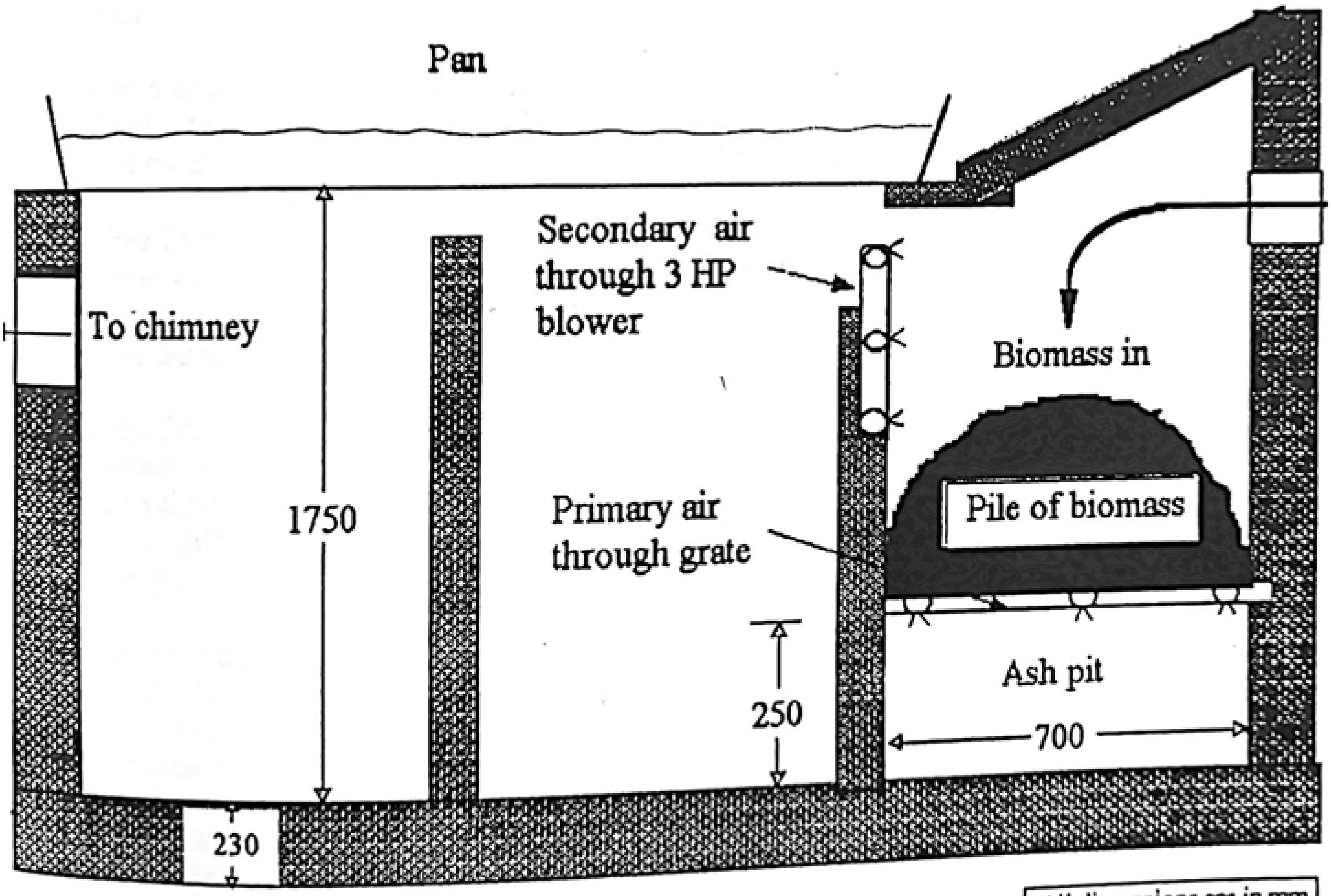
This model was tested under different experimental conditions. Thus, the primary and secondary air were varied from 0-100% of the total air supplied. The results were as follows :

(a) A high degree of turbulence was clearly visible in the combustion chamber. Swirling flow was observed as the high velocity secondary air jets penetrated the flame and resulted in excellent mixing of the air and the volatiles released from biomass. This indicated that the design of the primary and secondary air inlet manifolds was satisfactory.

(b) It was seen that combustion of wet bagasse (41 % moisture content) could be sustained after the furnace was operated for about two hours on dry fuel. Water boiling tests were then conducted with sweet sorghum bagasse and the results are shown in Table 3.3.



Sectional View of Plan



Sectional View of Elevation

All dimensions are in mm unless otherwise stated

Fig. 3.2 : Pilot scale Syrup making Furnace - Model I

Table 3.3 : WATER BOILING TESTS ON MODEL I

1. Sweet sorghum bagasse consumption rate	: 117.6 kg/h (wet)
2. Moisture content of bagasse	: 41% (w/w, wet basis)
3. Water boiling rate	: 84 kg/h
4. Air flow rate	
(a) Primary air	: 110 Nm^3/h
(b) Secondary air	: 225 Nm^3/h
5. Temp. of flue gas at base of chimney	: 370-450^{0}C
6. Combustion chamber wall temperatures	: Max 400^{0}C after five hours of operation
7. Thermal efficiency	: 15.6% (assuming a gross calorific value of 18 MJ/kg (dry) for bagasse)

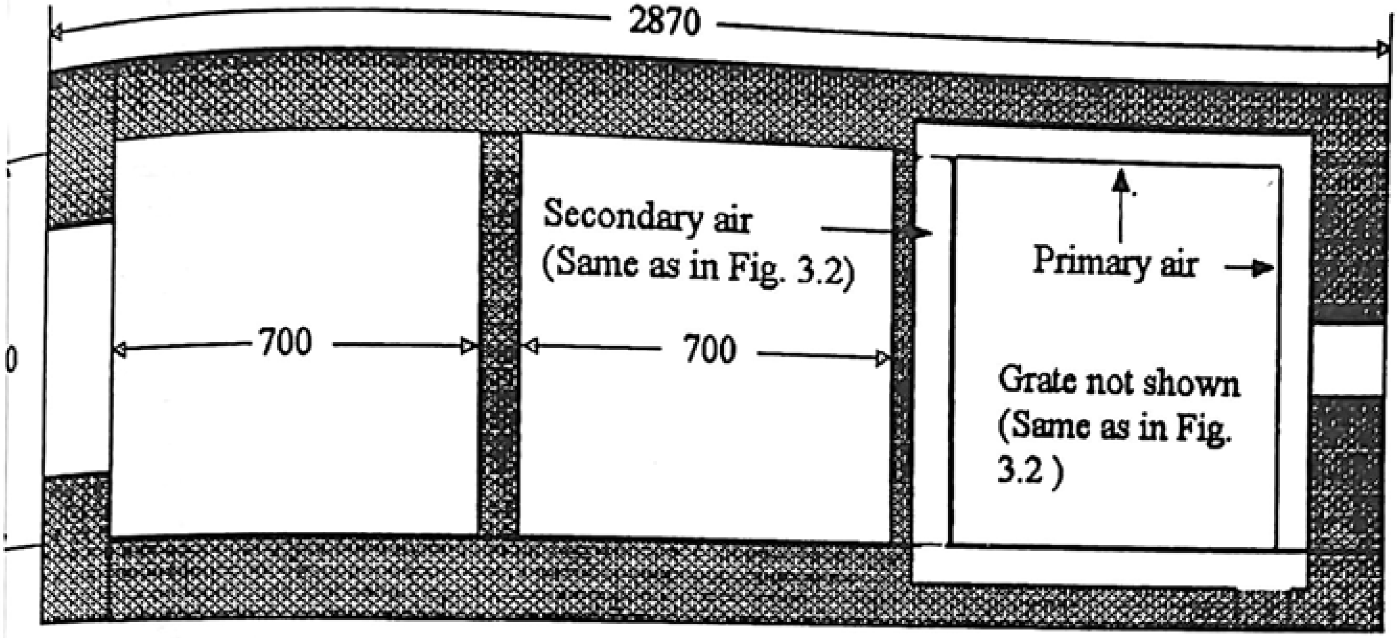
(c) The furnace was then tested with bagasse having 50% moisture (wet basis). It was seen that combustion could be sustained at a maximum bagasse consumption rate of 60 kg/h (wet basis) or 30 kg/h (dry-basis) corresponding to a gross heat release rate of ~ 530 MJ/h. At higher bagasse consumption rates, quenching of the combustion chamber was observed and combustion could not be sustained. Further, at 30 kg/h biomass consumption rate, there was no boiling of water in the pan. This meant that the furnace could not be used to make syrup or gur when operating on 50% moisture fuels.

(d) It was also tested with dry sugarcane leaves (~ 7% moisture). Considerable back pressure was developed at the feeding port, probably due to the extremely high combustion rate of dry fuels. This resulted in the fuel igniting in the feeding port itself, thereby constituting a fire hazard.

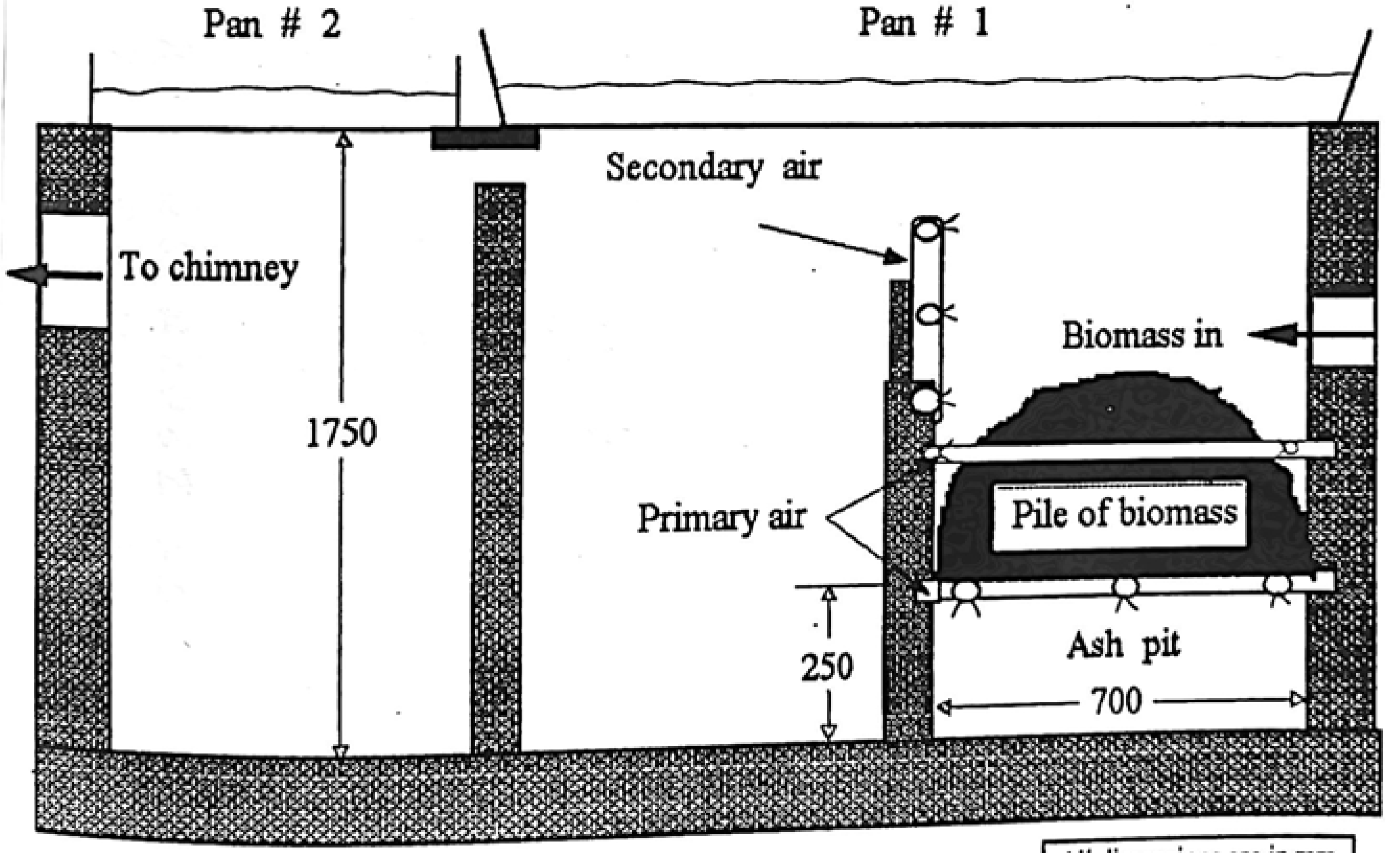
(e) When operating on wet fuels, slightly bluish stack gases were seen from the chimney, indicating lower combustion chamber temperatures than desired. Inspite of varying the primary and secondary air flow rates, the blue colour of the flue gases could not be fully eliminated. On the other hand, slightly black flue gases were seen when the furnace was operating on dry fuel.

Thus, the first attempt at developing a wet biomass combustor produced a design wherein partially wet bagasse with 41 % moisture content could be combusted with 15-16% efficiency (based on gross calorific value) and could be used to make syrup or gur. Further, though combustion of 50% moisture bagasse could be sustained, the heat release rate of 530 MJ/h was too low to be useful for producing syrup or gur.

It is also seen from Table 3.3 that even after five hours of operation, the maximum wall temperatures in the combustion chamber did not exceed 400^{0}C. This suggested that at least for gur or syrup-making furnaces, the role of hot refractory surfaces to facilitate drying and combustion of wet biomass would be rather limited. This is because typically these furnaces are operated for a maximum of 12-14 hours a day and are then closed down for the remaining 10-12 hours. Under these conditions, the furnace walls would only start contributing to the combustion process towards the end of the days' operation. For the major part of the operation, the walls would be a heat sink, absorbing heat rather than radiating it to the wet biomass. Thus, the presence of a separate combustion chamber did not seen desirable. This observation was also in line with the earlier findings of Shri. Jagjit Singh[10]. Drying of biomass, in the absence of any separate pre-drying facility, had therefore to be accomplished mainly by radiative and convective heat transfer from the hot glowing charcoal bed and the hot flue gases. Model II was therefore designed with this in mind.



Sectional View of Plan



Sectional View of Elevation

All dimensions are in mm
unless otherwise stated

Fig. 3.3 : Pilot scale Syrup making Furnace - Model II

(ii) **Model II :** In this model seen in Fig. 3.3, there was no separate combustion chamber. The pan was kept directly above the grate and extended to about 2/3 the length of the furnace. This pan, designated as Pan # 1, contained the juice used to make syrup or juice. A separate pan to sterilize the bottles was kept over the remaining 1/3 of the furnace (Pan # 2). The grate, the primary and secondary air inlet manifolds and the overall furnace dimensions of Model I were retained. However, primary air was also injected into the biomass pile from all sides through another manifold kept at a height of 25 cm above the grate. This is also seen in Fig. 3.3.

The salient features of its performance were as follows :

(a) This design could sustain combustion of bagasse containing on an average upto 50% moisture content, after it was operated for about two hours on dry fuel. In this model, the flame and the hot flue gases were forced to come into contact with the fresh and wet bagasse being fed through the feeding port. This resulted in quick drying of the wet material and so combustion could be sustained.

(b) It was found that intermittent agitation and poking of the pile inside the furnace was necessary to maintain combustion. To facilitate this, the position of the feeding port was changed from near the roof of the furnace to about 50 cm above the grate. Occasionally, dry fuel (sugarcane leaves) had to be added to prevent quenching.

(c) There was some amount of back pressure during wet fuel operation. This resulted in some unburnt volatiles exiting the furnace through the feeding port.

(d) No problems were encountered when the furnace was operated on dry sugarcane leaves. The operation was smooth and there was no back pressure through the feeding port during dry fuel operation.

(e) Slight amount of blue smoke was visible during operation with wet fuel. However, absolutely clear stack gases were emitted on dry fuel operation.

(f) The furnace was also tested on wheat straw and 'harbara' stalks. Both of them had been exposed to rain and so had ~ 50% moisture. Excellent performance was obtained on 'harbara' stalks, whereas very poor results were obtained on wheat straw. This suggested that the type of biomass fuel also plays an important role in determining the furnace performance, especially in the case of wet fuels.

(g) The results of the water boiling tests with dry sugarcane leaves (7% moisture content) and wet bagasse (55% moisture content) are given in Table 3.4.

TABLE 3.4 : WATER BOILING TESTS ON MODEL II

		Sugarcane leaves	Sweet sorghum bagasse
1.	Fuel Consumption,	35 - 63 kg/h (dry)	33 - 40 kg/h (dry)
2.	Moisture content,	7 % w/w (wet)	42 - 55 % w/w (wet)
3.	Water boiling rate,	45 - 93 kg/h	50 - 55 kg/h
4.	Temperature,		
	(a) Combustion zone	650 - 750 °C	600 - 750 °C
	(b) Base of Chimney	325 - 450 °C	275 - 400 °C
	(c) Wall Temperature in combustion zone after six hours of operation	400 °C	400 °C
5.	Thermal efficiency		
	(a) Pan # 1	13.6 - 18.20 %	15.5 - 17.6 %
	(b) Pan # 2	3.4 - 4.5 %	2.5 - 2.9 %
	(c) Overall	17 - 22.7 %	18 - 20.5 %

It is seen from Table 3.4 that the temperature of the flue gases at the base of the chimney was 325-450 °C. This was the lowest temperature which could be attained while sustaining vigorous combustion in the bagasse-fired furnace. This temperature was lower than 500 °C reported for other similar furnaces[10]. Heat transfer calculations showed that very large heat transfer areas would be required to recover the heat from the flue gases exiting the furnace at 450 °C. This was not considered to be feasible in the absence of an induced draft fan, and so the flue gas temperature of 450 °C may represent the most economical temperature for these furnaces.

Further, the effect of having an additional pan (Pan # 2) on the overall thermal efficiency is also clearly evident from the data presented in Table 3.4. Thus, the efficiency of the system increased from 13.6 - 18.2 % when only one pan (Pan # 1) was considered to 17 - 20.5 % when both the pans were considered. Thus, the additional pan increased the overall system thermal efficiency by about 2.5 - 4.5 percentage points.

It is also seen from Table 3.4 that a water boiling rate of 50-55 kg/h was reached even on operation with sweet sorghum bagasse with a maximum of 55% moisture content. This suggested that the furnace could be used to make syrup using wet bagasse.

Accordingly, this furnace was used to make syrup from sweet sorghum. A typical result of one batch is given in Table 3.5.

TABLE 3.5 : SYRUP PRODUCTION DATA ON MODEL II

1.	Whole of stalks	1525 kg
2.	Stripped stalks	1079 kg
3.	Juice extracted	370.5 kg
4.	Juice rejects	17.2 kg
5.	Scum removed	22.8 kg
6.	Syrup produced	69.6 kg
7.	Bagasse generated	280 kg (dry)
8.	Water required to be removed	260.4 kg (0.93 kg/kg bagasse)
9.	Fuel required	
	(i) Bagasse	500 kg with 55% moisture content (225 kg dry)
	(ii) Sugarcane leaves	137.7 kg with 30% moisture content (96.4 kg dry)
	(iii) Total	637.7 kg with average 49.6% moisture (321.4 kg dry) or 4.62 kg (dry)/kg syrup
10.	Weight of water actually boiled of	323.8 kg or 1.01 kg/kg bagasse (dry)
11.	Batch time	5.33 hours
12.	Overall furnace efficiency	14.33 %

It can be deduced from the above table that tbe biomass consumption rate was 60.3 kg (dry)/h, corresponding to a heat release rate of 1085 MJ/h. Further, it is also seen that the total fuel consumption of 321.4 kg (dry) exceeds the amount of bagasse generated (280 kg dry). Thus, it appears as if the furnace is not self sufficient in its fuel requirement.

However, it should be kept in mind that only 2/3 of the furnace was being used for actual syrup production (Pan # 1). The remaining 1/3 of the furnace was used to sterilize the bottles used to fill the syrup (Pan # 2). These empty bottles were kept immersed in boiling water in this pan for about one-two hours and were then oven-dried. When this data was being recorded, only water was filled in this pan and the amount of water boiled of from this pan during the time the syrup was being made was then monitored. Thus, the amount of water actually boiled of (323.8 kg) was different from the amount of water required to be boiled of (260.4 kg) to make 69.6 kg syrup.

For proper interpretation of the data, therefore, comparison was made between the amount of water required to be removed vis-a-vis the amount of bagasse available for this purpose and the actual experimental values for them. From Table 3.5, it is thus seen that to attain fuel sufficiency, all the bagasse (280 kg dry) generated from 1079 kg of stripped stalks should be sufficient to boil of 260.4 kg water, i.e. 0.93 kg water should be boiled of per kg of dry bagasse consumed. This translates into a required thermal efficiency of 13.2 % on gross heating value of dry sweet sorghum bagasse (18 MJ/kg). The actual experimental data showed that 1.01 kg of water were boiled per kg fuel (dry), which corresponded to a thermal efficiency of 14.33 %. Since this exceeded the target fuel efficiency, it was surmised that this furnace was self sufficient in its fuel requirements. In subsequent discussions also, the fuel sufficiency of the furnace for syrup production was determined in this manner.

From the above discussion, it is apparent that the design of Model II could not only sustain wet bagasse combustion with an average moisture content of 50%, but that it was also self-sufficient in its fuel requirements for making syrup from sweet sorghum. However, there was scope for further improvement. A slight amount of blue smoke was still visible during wet fuel operation. Another drawback in this design was that there was some back pressure in the feeding port due to the extreme turbulence created by the secondary air jets. This resulted in some unburnt volatiles and hot flue gases exiting the furnace through the feeding port. This not only made biomass feeding a very inconvenient task but also constituted a significant thermal loss. It was mainly to reduce this back pressure and increase the ease of operation of the furnace that Model III was designed and tested.

Model III : This model seen in Fig. 3.4 incorporated some salient features of Models I and II. It had a rear arch to provide radiative heat to the pile of wet biomass. Two variations of this model were experimented with, the major difference being the length of the rear arch. In the first version (Model IIIa), the rear arch extended to cover 30% of the furnace opening and in the second version (Model IIIb), it covered 55% of the furnace opening. As seen in Fig. 3.4, the secondary air jets were aligned along this rear arch, so that they penetrated the flame at an angle of ~ 30°. Further, the secondary air jets were located at a greater distance from the feeding port as compared to the earlier models. This was to minimize the back pressure through the feeding port without reducing the turbulence and the excellent mixing of air and volatiles achieved in Models I and II.

Salient features of its performance were as follows :

(i) Combustion of bagasse with 49% moisture could be sustained in this model. Drying of wet bagasse was quite rapid owing to the radiative heat from the rear arch wall. This effect was clearly noticeable after the furnace was in operation for about two hours in Model IIIa. It was found that there was a marginal improvement in combustion stability in the version with the bigger arch (Model IIIb). However, it required more time (approximately four hours) to heat up and also increased the pressure drop of the furnace. This resulted in a greater degree of back pressure at the feeding port.

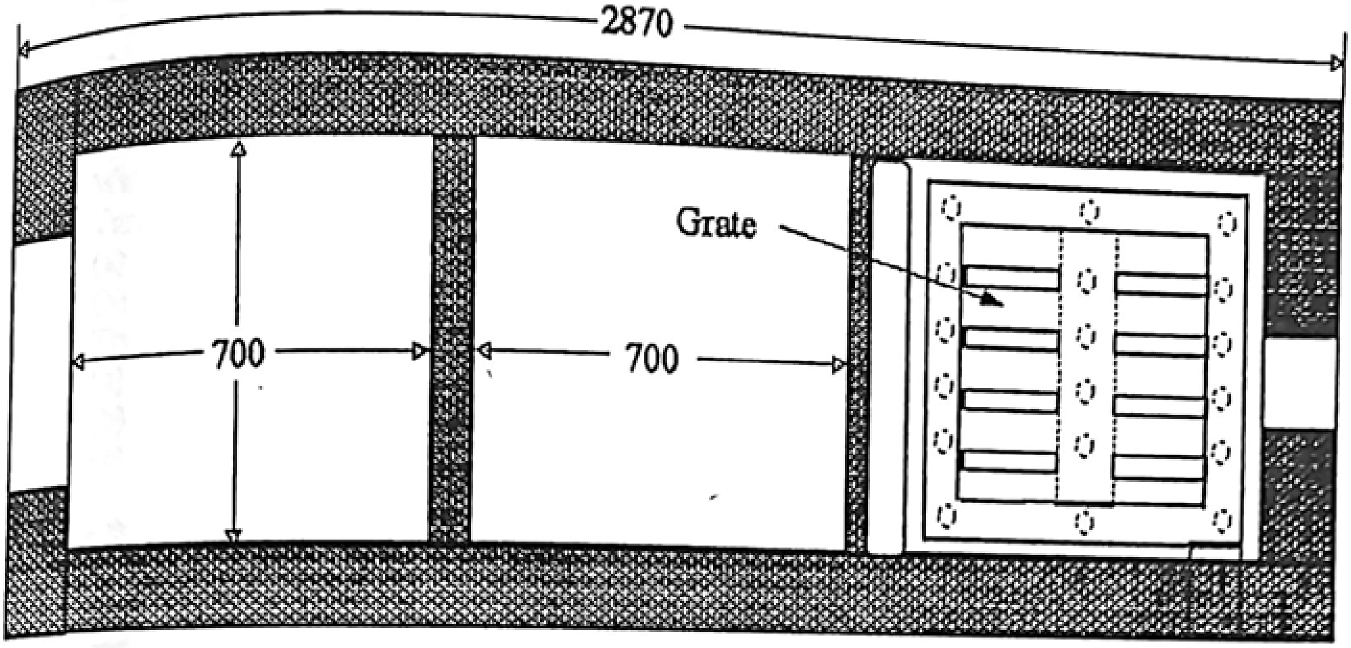
(ii) It was found that presence of a 30-50 cm thick hot charcoal layer was absolutely essential to maintain combustion. Radiation from the furnace walls, by itself, was not sufficient to dry and ignite the wet fuel, even after five-six hours of operation.

(iii) Poking of the bed was necessary since the distance between the feeding port and the rear arch was nearly 1 m. This made the operation of the furnace slightly more laborious as compared to the previous models.

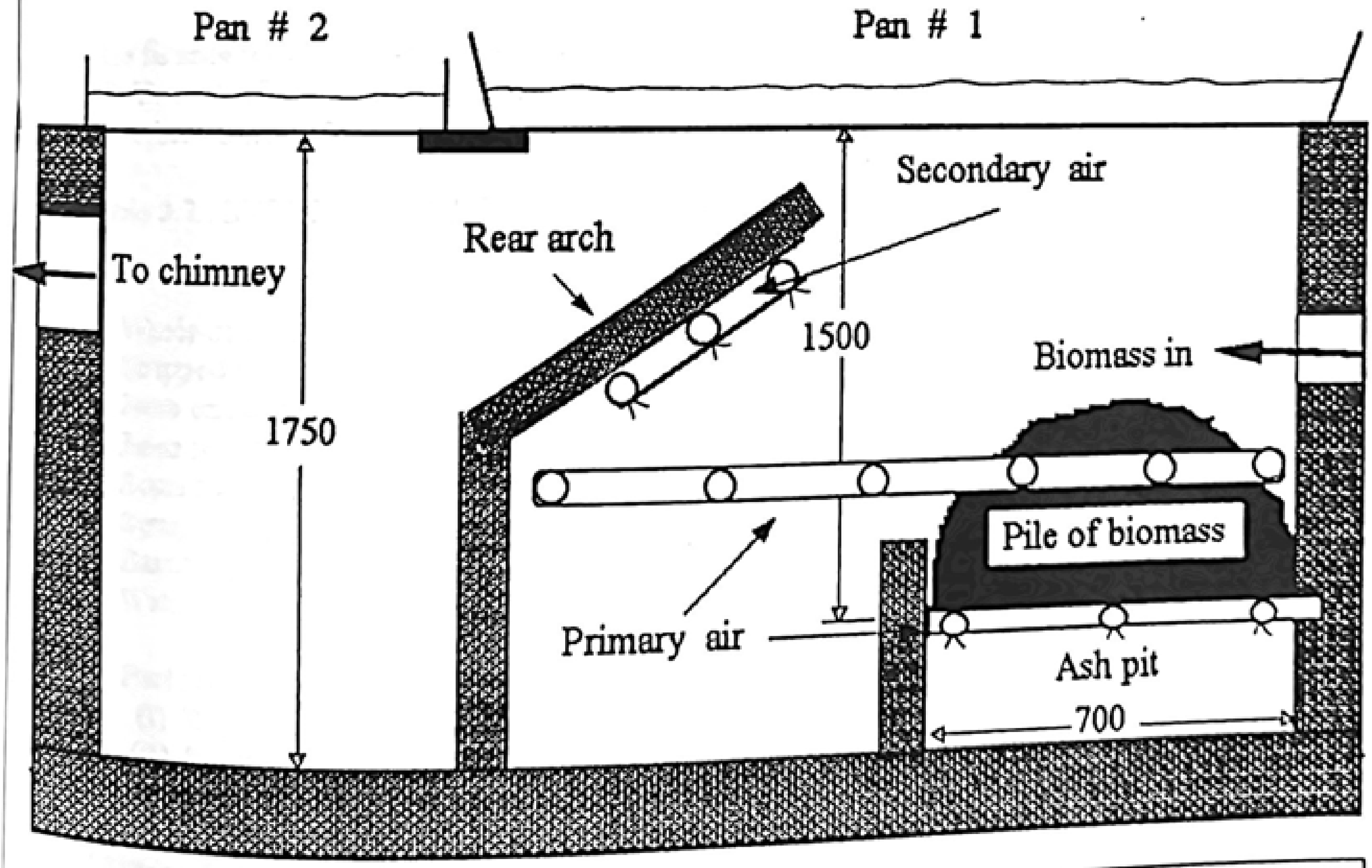
(iv) There was no back pressure if the secondary air from the rear arch wall was reduced, but this was not conducive to wet bagasse combustion. The jet velocities had to exceed 20 m/s for good combustion, and under these conditions, the back pressure through the feeding port was considerably reduced, but could not be fully eliminated. This was true for both Model IIIa and Model IIIb.

(v) Model IIIa was found to be superior to Model IIIb for operation on dry fuel mainly because it offered more free volume for combustion. There was no back pressure through the feeding port on dry fuel operation.

Thus Model IIIa was better suited for making syrup than Model IIIb owing to its ability to handle both wet and dry fuels and because of the comparatively shorter start-up time of about two hours. So water boiling tests were conducted on Model IIIa, the results of which are given in Table 3.6.



Sectional View of Plan



Sectional View of Elevation

All dimensions are in mm unless otherwise stated

Fig. 3.4 : Pilot scale Syrup making Furnace - Model III

TABLE 3.6 : WATER BOILING TESTS ON MODEL IIIa

1. Fuel used	Sugarcane leaves
2. Biomass consumption	56 - 58 kg/h (dry)
3. Moisture content	18 % w/w (wet)
4. Water boiling rate	100 - 110 kg/h
5. Temperature	
(a) Combustion zone	700 - 900 °C
(b) Base of chimney	425 - 550 °C
6. Thermal efficiency	
(a) Pan # 1	18.3 - 20.2 %
(b) Pan # 2	5.20 - 5.4 %
(c) Overall	23.5 - 25.6 %

It is thus seen that the overall efficiency of this furnace came to 23.5 - 25.6 %, with Pan # 1 contributing 18.3 - 20.2 %, and Pan # 2 accounting for the remaining 5.2 - 5.4 %. Thus, this model had the highest overall thermal efficiency amongst the three models evaluated in this study (refer to Tables 3.3 and 3.4).

Another important feature of this model was that higher combustion zone temperatures of 700 - 900 °C were reached in Model IIIa as compared to 600 - 750 °C in Model II (refer Table 3.4). This was attributed to the radiative heat from the rear arch, and was the main factor in facilitating combustion of wet bagasse.

This furnace was then used to make syrup from sweet sorghum. The results are presented in Table 3.7. Two sets of data were generated - one where the average moisture content (MC) was ~ 49 % and one where it was 40 %. These are designated as Run # A and B respectively in this table.

Table 3.7 : SYRUP PRODUCTION DATA ON MODEL IIIa

	Run # A	Run # B
1. Whole of stalks	Not measured	1344.5 kg
2. Stripped stalks	983 kg	957.1 kg
3. Juice extracted	346 kg	366.5 kg
4. Juice rejects	13.4 kg	23.2 kg
5. Scum removed	25.2 kg	34.5 kg
6. Syrup produced	60.7 kg	65.7 kg
7. Bagasse generated	287 kg (dry)	265.8 kg (dry)
8. Water required to be removed	246.7 kg (0.861kg/kg syrup)	243.1 kg (0.915 kg/kg syrup)
9. Fuel required		
(I) Bagasse	400.7 kg with 55%	140 kg with 55%
(ii) Sugarcane leaves	268.3 kg with 39%	319 kg with 33% MC
(iii) Total	669 kg with 48.6% moisture (343.9 kg dry)	467 kg at 40% MC (280.2 kg dry)
10. Specific Fuel Consumption	5.67 kg (dry)/kg syrup	4.26 kg (dry)/kg syrup
10. Weight of water actually boiled of	314.5 kg or 0.91 kg/kg bagasse	328.6 kg; or 1.17 kg/kg bagasse
11. Batch time	4 hours	4 hours
12. Overall system efficiency	12.9 %	16.6 %

It can be deduced from the above table that the biomass consumption rate was 86 kg/h (dry) and 70 kg (dry) in Run # A and # B respectively. Thus, the maximum heat release rate of the furnace came to 1500 MJ/h (420 kW).

It is also seen that the fuel economy of the furnace varies with the average moisture content of the fuel used. Thus, in the case where the average moisture content was 48.6 %, about 0.91 kg of water was boiled of per kg of dry fuel consumed. However, this increased to 1.17 kg water removed/kg dry fuel consumed when fuel with an average moisture content of 40% was used. The corresponding overall system efficiencies came to 12.9 % and 16.6 % respectively.

Further, it is evident from Table 3.7 that a mix of 55 % moisture bagasse and partially dry (33-39 %) sugarcane leaves was used to make syrup. This was found to be necessary to prevent quenching of the combustion zone temperatures. It was thought that increasing the refractory surface would obviate the need for doing this. However, operation of one complete batch using only wet (55% moisture) bagasse could not be achieved during this project. The maximum time of operation on only wet bagasse was 90 minutes, after which some partially dry (upto 40% moisture) fuel had to be introduced into the furnace to maintain the temperatures above the ignition temperatures of the fuel.

With the completion of these tests, the developmental work on wet bagasse combustors was deemed to be complete. The major objectives of sustaining wet bagasse combustion and attaining fuel self-sufficiency during syrup production from sweet sorghum were largely met. All the data presented here have been compiled and analysed in the next chapter.

3.2 Gur-making Circular Furnace

Though not a part of the objectives of the project, data were collected regarding the fuel efficiency of a commercial-scale gur-making furnace. Based on these data, a scaled-down version of this circular furnace was constructed and tested at NARI. These results are described below.

3.21 Commercial scale Gur-making Furnace

This furnace was fitted with a blower and grate arrangement. The gur manufacturer reported the following advantages with this arrangement over the previous natural draught operation.

(a) Due to vigorous and efficient combustion, the batch time was reduced from the earlier 3-3 ½ hours to 2-2 ½ hours. Thus, he could make one-two extra batches of gur per day, which had a significant effect on his profitability.

(b) The extent of black smoke from the chimney was greatly reduced. He reported that for most part of the operation, there was practically no visible smoke.

(c) There was a noticeable increase in the fuel economy of the furnace. Earlier, he had to resort to extra fuel in the form of sugarcane leaves or other farm wastes. However, with the blower-grate arrangement, he reported that the furnace was practically self-sufficient in its fuel requirements.

Data were then taken when the actual gur-making process was in full swing. These data are presented below in Table 3.8.

Table 3.8 : GUR PRODUCTION DATA IN A COMMERCIAL GUR-MAKING PLANT

Data refers to the fourth batch of the day.

1. Sugarcane stalks	1300 kg
2. Sugarcane tops	30 kg
3. Juice extracted	786 kg
4. Brix of juice	18 degree
5. Fresh bagasse generated	484 kg at 59% moisture content or **198 kg (dry)**
6. Bagasse consumed in furnace	226 kg at 6.1% moisture content; or **212 kg (dry)**
7. Net Fuel Economy	Deficit of 14 kg (dry)
8. Gur produced	141 kg
9. Time required for	
(a) Crushing	40 min
(b) Pan boiling	135 min
(c) Finishing and filling in 1 kg moulds	90 min
10. Furnace efficiency	42 %

The salient features of the performance were as follows :

(a) The juice extraction with the Vasant # 3 crusher was nearly 62% on weight basis for a single pass operation. This was a very good performance, and it was seen that the bagasse was reduced to almost a powdery form. The gur manufacturer claimed that he could increase the extraction even further, but then, the bagasse becomes so powdery that much of it gets lost in drying and handling it. So he preferred to minimize the bagasse loss rather than to maximize juice extraction.

(b) The weight of bagasse obtained from 1270 kg sugarcane stalks came to 198 kg (dry), or 15.6% on stalk weight basis. This is lower than 18.75% which was used for estimation purposes (Refer Table 2.5).

(c) The furnace operation on bagasse with the blower-grate arrangement was exceedingly simple and convenient. Ash was disturbed and the grate cleared only after every batch. The ash was greyish white in appearance, indicating a very high carbon conversion efficiency.

(d) Only occasionally, when the furnace was 'over-loaded' was there black smoke from the chimney. For the greater part of the operation, there was practically no visible smoke.

(e) The gur manufacturer claimed that even less fuel than that recorded was normally required. The sugarcane crop used in this batch was not ideal for making gur because it was exposed to heavy rainfall just a week before harvest. So the brix of the juice was lower than normal. This was borne out by data wherein the brix of the juice was determined to be only 18^0.

(f) A significant feature observed was that the fuel had to be ignited both when the fourth and fifth batches were started. There was no char bed on the grate at the beginning of the batch, and so, it was clearly seen that the furnace walls do not radiate sufficient heat to ignite even dry bagasse. Thus, it was clear that the furnace walls act only as insulators, and could not be expected to contribute significantly to the combustion of dry (or wet) fuel.

It is seen from Table 3.8 that 212 kg (dry) bagasse was consumed, whereas 198 kg (dry) bagasse was generated. Thus, there was a net shortfall of only about 14 kg (dry) bagasse. It is expected that if the brix of the juice was around 20^0, then, full self-sufficiency would have been attained.

The thermal efficiency of the furnace was deduced from the amount of water evaporated and the total bagasse consumed. Out of 786 kg of juice, 141 kg of gur was produced. Though 47 kg of scum was removed, almost an equal quantity of bhendi mucilage and juice from the previous batch were added. Thus, about 654 kg of water were boiled of. Since 212 kg (dry) bagasse was consumed in this process, the thermal efficiency of the furnace for this batch came to 42% (assuming a gross calorific value of 18.56 MJ/kg for dry bagasse).

It is instructive at this stage to compare this performance with those reported elsewhere for gur making. The double grating Annakapalle furnace[15] reported a fuel consumption of 35-39% of air-dry bagasse on juice weight basis, as compared to only 28.8% in the present furnace. Thus, the present furnace is a significant improvement over the Annakapalle furnace.

Further, Chockalingam[40] gave a comparative performance of three types of furnaces as shown below in Table 3.9.

Table 3.9 : PERFORMANCE OF JAGGERY MAKING FURNACES[40]

Details	Sindewahi furnace	Improved Poona furnace	Pugalur furnace
Juice weight per boiling,	216 kg	600 kg	626 kg
Time taken for each boiling	2.02 hours	2.16 hours	1.43 hours
Quantity of juice boiled per hour	106 kg	263 kg	365 kg
Average time taken for boiling 1000 kg juice	9.26 hours	3.48 hours	2.44 hours
Percentage of fuel on the juice weight	46 %	50 %	53 %

It is seen from this table that the minimum fuel consumption of 46% on juice weight basis was reported for the Sindewahi furnace. It was not clear from the article whether this referred to air-dry weight or fresh (wet) weight of the bagasse. However, since all these furnaces were designed to operate on dry fuels only, it was assumed that the fuel consumption data were on air-dry weight basis. In that case, the Sindewahi furnace was even poorer than the Annakapalle furnace.

There were some reports on the IISR furnace[46, 47], but the fuel consumption data were not given. Thus, it appears as if the present furnace is more efficient than all the other gur-making furnaces for which data were available.

Further, there were reports of improved furnaces used in the open pan sugar manufacture. These were typically three to five pan systems and had a boiling capacity of 700-1100 kg/h. Their performance data are given in Table 3.10[10].

Table 3.10 : PERFORMANCE OF FURNACE USED IN OPEN PAN SUGAR MANUFACTURE [10]

	'Standard' Bel (Ghosi Design) 5 pans + 2 Gutter pans	Rohilkhand 'Bel' 4 pans + 1 Gutter pan	Improved Meerut 'bel' 3 pans + Gutter pan
1. Boiling capacity, kg juice/h	780	777	1125
2. Bagasse Consumption			
(a) kg/h (dry)	194	200	154
(b) kg (dry) / h.m^2 of grate area	521	526	403
3. Water evaporated, kg/kg bagasse (dry)	3.2	3.06	2.5
4. Heat transfer efficiency, %	43	41	34
5. Chimney exit temperature, ^{0}C	390-410	525	506
6. Heating surface provided, m^2	8.78	15.9	8.29
7. Capacity provided, m^3	1.11	3.62	1.17
8. Heating surface / capacity; m^2/m^3	7.	4.39	7.09

It is seen that the maximum efficiency of these furnaces was reported to be 43%, only marginally more than the present furnace efficiency of 42%. However, this furnace designated as 'Ghosi' Design had five pans and provided a large heating surface to volume ratio of 7.91 m^2/m^3. In the present furnace, this ratio came to 6.96 m^2/m^3, which was about 12% less than that provided in the 'Ghosi' design. It was felt that with the inclusion of an additional pan or a heat recovery device, the efficiency of this furnace could have been increased even further. However, this entailed major changes/modifications in the plant layout. The gur manufacturer was not very keen to effect these changes for the sake of an additional 5-10% increase in efficiency. He was satisfied with the fact that his furnace was almost self-sufficient in its fuel requirements. He did not mind having to bring in an occasional load of sugarcane leaves, but he was averse to the idea of modifying his plant layout.

Following this on-site monitoring of the furnace performance, further experiments were carried out on a scaled-down version of this furnace at NARI. These results are described below.

3.22 Pilot-scale Gur-making Furnace at NARI

A pilot scale circular furnace (50 kg gur/batch) was constructed at NARI. After its commissioning was completed, water boiling tests with dry sugarcane leaves were conducted. The salient features of this performance were as follows :

(a) Excellent swirling flame was observed in the combustion chamber.

(b) There was no back pressure from the feeding port. This meant that the chimney provided sufficient draught to evacuate the flue gases.

(c) Absolutely no smoke was visible when operating on dry sugarcane leaves. However, the presence of fly-ash and unburnt char particles in the flue gas was clearly seen. Thus, a gravitational settling chamber may prove necessary to reduce the extent of fly ash in the flue gases.

(d) The temperature at the base of the chimney reduced from 500-650^{0}C (when tertiary air was not used) to 350-450^{0}C when tertiary air was used.

(e) It was experimentally determined that the maximum moisture content of bagasse which could be combusted on a sustained basis in this furnace was 40%. No attempt was made to modify the furnace internals to combust higher moisture containing bagasse since the primary objective was to have high efficiency on dry fuels.

The results of the water boiling tests are given in Table 3.11.

Table 3.11 : WATER BOILING TESTS ON CIRCULAR FURNACE

1. Fuel used	Sugarcane leaves
2. Fuel consumption	40 - 60 kg/h (dry)
3. Moisture content	6 - 7 % w/w (wet)
4. Water boiling rate	192 - 133 kg/h
5. Temperature	
(a) Combustion zone	800 - 1000 ^{0}C
(b) Base of chimney	500 - 450 ^{0}C
(c) Top of chimney	300 - 350 ^{0}C
6. Thermal efficiency (after two hours of operation)	26 - 30 %

It is seen from Table 3.11 that a maximum of 30% efficiency was obtained after the furnace was in operation for two hours prior to the test run. This is a definite improvement over the rectangular furnaces, where the maximum efficiency was ~ 25.6 % for the direct combustion furnace (Refer Section 3.12). This is even greater than the 28.6 % which can conceivably be achieved for the gasifier-furnace system (Refer Section 3.11).

However, it is seen that this is considerably lower than the efficiency of 42% estimated on the commercial gur-making furnace with blower-grate arrangement (Refer Section 3.21). This may be attributed to the fact that the commercial furnace offered a greater cross-sectional area to volume ratio of 5.47 m^2/ m^3 of furnace volume than the scaled down version (1.33 m^2/m^3 furnace volume). Thus, the commercial furnace offered much more exposed area of the pan for heat transfer than the scaled-down version. This was the adverse effect of the scaling-down process. If the same ratio of 5.47 m^2/m^3 of furnace volume was to be maintained for a 1.3 m diameter furnace, the height of the furnace had to be only 24 cm. This was not practical and so the efficiency obtained on the commercial furnace could not be achieved in the pilot scale furnace.

Following the water boiling tests, gur was then made on this furnace. Excellent quality of gur both in terms of colour and taste was produced without the use of any chemicals. Factors which contributed to this were as follows :

(i) The pan and other vessels which came in contact with the juice were made of stainless steel. In the commercial plant, all the vessels were made of mild steel, which has been known to impart dark colour to syrup and gur [16].

(ii) An effective juice clarification system described in Section 2.2 was developed. Due to the elaborate filtration system, the juice was no longer settled for one to two hours. It was taken to the pan immediately after the crushing was over. This helped to contain the sucrose inversion, thereby improving the gur quality.

(iii) The heating rate was carefully regulated, especially towards the end when the brix increases beyond 70-75°. The entire mass was slowly agitated along the bottom of the pan to prevent caramelisation and 'burning' of gur. This method was very effective in preventing this phenomenon, thereby belying initial apprehensions that gur may get 'burnt' in a stainless steel pan.

(iv) Vigorous working of the hot-mass in the finishing pan was employed. This was mainly responsible for imparting the desirable yellowish colour to the gur.

During the process of gur making, data were collected on the fuel consumption of the furnace. It was realised that the thermal efficiency of the furnace would increase with each successive batch on a given day as the furnace approaches steady state conditions. To quantify the reduction in fuel consumption per kg of gur produced, two successive batches of gur were made. This was the maximum number of batches which could be produced in a day, given the logistical constraints at NARI.

The furnace was operated on both sugarcane leaves and bagasse (both air-dry). It was found that there was significantly more fly-ash problem on sugarcane leaves than on operation with dry bagasse. Moreover, the furnace volume also got filled up very quickly with ash in case of sugarcane leaves.

A typical data sheet for two successive batches is given below in Table 3.12. The amount of dry bagasse generated was assumed to be 15.6% on stalk basis. This data were obtained both on the commercial gur plant and at NARI.

Table 3.12 : PILOT SCALE GUR PRODUCTION DATA

	Sugarcane leaves		**Bagasse**	
	Batch I	Batch II	Batch I	Batch II
1. Sugarcane stalks, kg	438	439	432	438
2. Juice, kg	219	228	242	214
3. Bagasse generated, kg (dry)	68.5	68.5	67.5	68.5
4. Gur, kg	39.9	45.6	37	43.7
5. Fuel required, kg (wet)	150.2	116.7	133.3	101.1
6. Moisture content, % w/w (wet)	14.7	7.7	8.75	7
7. Fuel required, kg (dry)	128	107.7	121.6	94
8. Specific Fuel consumption, kg (dry)/kg gur	3.21	2.36	3.29	2.15
9. Net Fuel Balance, kg	- 59.5	- 39.2	- 54.1	- 25.5
10. Furnace efficiency, %	21.4	25.95	23.3	25

It is thus seen from Table 3.12 that considerably less fuel is required in the second batch of the day as compared to the first. Thus, in case of sugarcane leaves, the fuel consumption reduced from 3.21 kg/kg gur to 2.36 kg/kg gur; whereas in case of bagasse, the reduction was from 3.29 kg (dry)/kg gur to 2.15 kg (dry)/kg gur.

It is also evident that the furnace has a negative fuel balance, i.e. more fuel is consumed than that generated in processing juice to make gur. In the case of sugarcane leaves, there was a deficit of 59.5 and 39.2 kg for the first and second batches respectively, whereas in case of bagasse, the deficit was 54.1 and 25.5 kg (dry) respectively. In subsequent batches, the fuel consumption could be expected to be reduced even further.

In terms of the thermal efficiency of the furnace, the maximum efficiency during the gur making process was ~ 26 % on sugarcane leaves and 25% on bagasse (assuming a gross calorific value of 16.72 MJ/kg for sugarcane leaves and 18.56 MJ/kg for sugarcane bagasse). Thus, this was less than the target efficiency of 45.6 % to attain fuel self-sufficiency during gur production from sugarcane.

It is thus seen that the smaller NARI furnace could not match the efficiency of the commercial scale furnace. This meant that any efforts to improve the efficiency beyond 42 % need to be carried out on the commercial scale furnace itself. Since this was beyond the scope of the present project, this research activity was not undertaken in the present study.

Even though not a part of the original objectives, some preliminary investigations were made into production of syrup from sugarcane. This was the logical outcome of the earlier finding that syrup provided substantially more value addition than gur in case of sweet sorghum. A similar phenomenon was also possible with sugarcane. It was thought that a similar scientific approach as was adopted for developing the technology for producing sweet sorghum syrup was necessary in case of sugarcane syrup.

Presently, most of the sugarcane syrup is produced by using indiscrimate quantities of different chemicals. Moreover, the processing technology used is the same as that for gur. However, Patil et al.[48] reported some promising developments in producing sugarcane syrup. Further, a private research Institute based in Pune [49] claimed to have a know-how for producing excellent quality of sugarcane syrup. In both cases, however, a certain amount of chemicals were used, either to facilitate clarification of juice or to impart good colour to the syrup. However at NARI, absolutely no chemicals were added at all even during gur manufacture, and it was decided to evaluate the quality of syrup produced using this process.

During the process of gur making, some samples of syrup were also withdrawn at the appropriate stage (when the brix was 70-75°). The following observations were made :

(a) The sugarcane syrup contained both floating and settled impurities. After about 24 hours of settling time, these two phases separated out leaving a clear transparent syrup layer in the middle of the bottle. This clearly showed that all the foreign impurities were not removed during the process. Thus, the juice clarification system and the process of scum removal were not sufficient to obtain clear syrup in case of sugarcane.

(b) Mold attack was seen after about a week of storage. This meant that certain preservatives may need to be added, unlike in the case of sweet sorghum syrup where no chemicals at all are added, and yet the syrup retains its original taste and colour even for upto one year.

(c) Formation of crystals was observed after about two-three days.

These preliminary findings suggested that the method of preparing syrup from sugarcane differs to some extent from that used for sweet sorghum syrup. Thus, certain modifications are needed in the process design used for sweet sorghum syrup to make it suitable for preparing syrup from sugarcane. This process development may be attempted in a separate project.

CHAPTER IV

RESULTS AND DISCUSSIONS

This chapter contains an overview of the work done in this project. All the data presented in the previous chapter are collated and analysed in this chapter. Thus, the salient features of the pilot scale syrup producing plant are first outlined. This is followed by a comparison of the performances of the different furnaces developed in this study. An economic analysis for syrup production from sweet sorghum on this pilot scale has also been attempted. Finally, the results of the data regarding gur production from sugarcane on the commercial-scale and on the pilot scale operations are collated and analysed in this chapter.

4.1 Production of Sweet Sorghum Syrup in the Pilot Plant

The salient features of the pilot plant are first outlined followed by an economic analysis for pilot scale production of sweet sorghum syrup.

4.11 Pilot Plant Performance

A pilot scale plant producing 50-70 kg syrup from sweet sorghum was set up at NARI. This is seen in Fig. 4.1. The material flow chart for this plant for syrup production is given in Fig .4.2.

The salient features of this plant are :

a. Excellent quality of sweet sorghum syrup can be produced in this plant. The syrup is clear and has an attractive and transparent appearance, as can be seen in Fig. 4.1.

b. A high quality of hygienic standard is maintained in this plant. All the equipments are made of stainless steel. Moreover, the clear and tasty syrup is produced without using any chemicals at any stage during the manufacturing process and so, a natural product is obtained. This was possible due to the development of a good processing protocol and tight quality control.

c. The entire process is extremely stream-lined. A detailed production protocol for this plant has been drawn up, including the activity-time chart thereby attaining a high degree of labour productivity. Three male and two female labourers are required per shift of eight hours.

d. It is equipped with two sources of heat-one is the gas-fired furnace where producer gas is burnt, and the second is the direct combustion furnace where wet bagasse can be directly combusted. Both these furnaces are designed for rectangular pans. There is also a circular pan-furnace system for use with dry fuel (like sugarcane leaves, dry bagasse or other dry farm wastes like bajra stalks etc.). Thus, this plant is equipped to effectively utilise almost any form of biomass wastes for producing syrup.

e. The plant is capable of producing both syrup and gur from sweet sorghum and sugarcane respectively. Thus, it can utilise a combination of both these crops so that it can be operated almost throughout the year (except during the monsoon, when the limitation is of harvesting the crop and not the operation of the plant *per se*). This makes more economic sense than having to

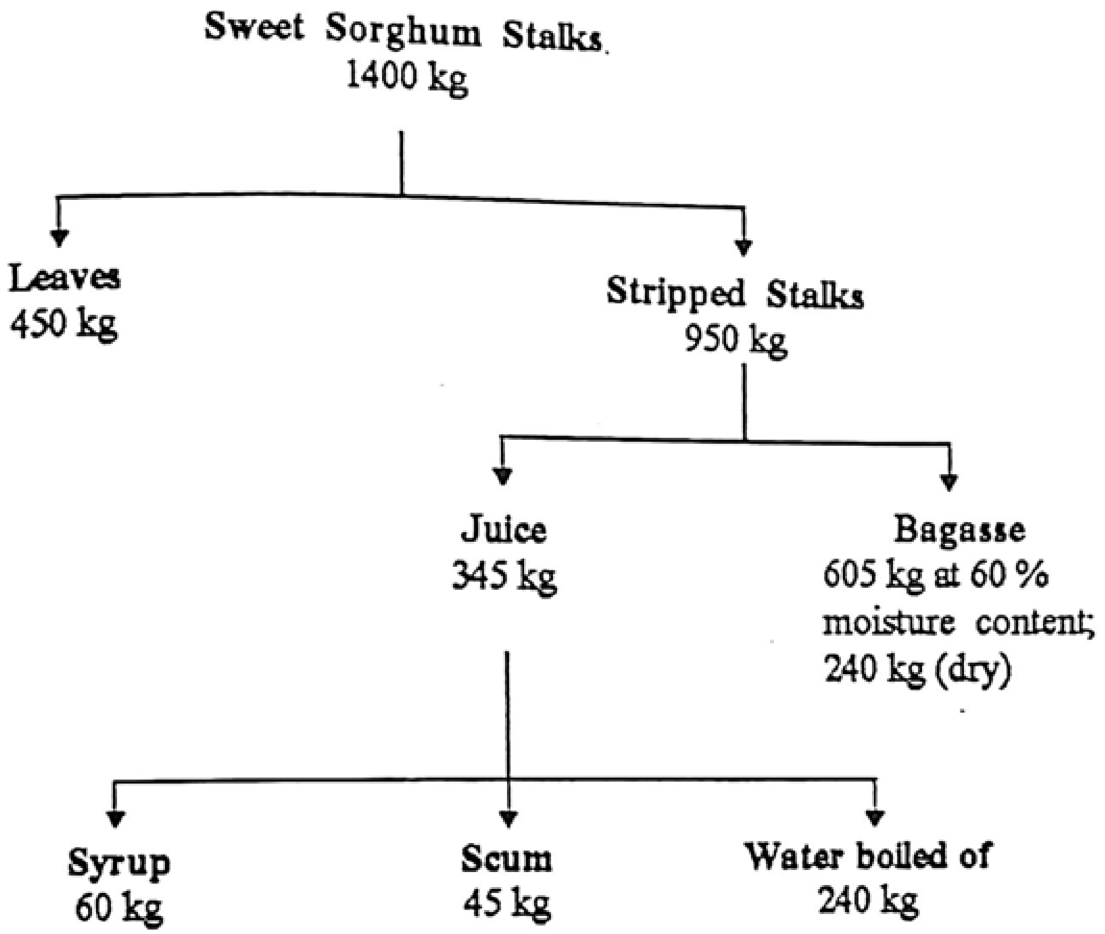
Crusher and Juice Clarification System

Sweet Sorghum Syrup-making Furnace

Fig. 4.1 : Pilot scale Syrup making Plant at NARI (contd. on next page)

Sweet Sorghum Syrup

Fig. 4.1 (contd.) : Pilot scale Syrup making Plant at NARI



Bagasse availabilty : 10 kg (wet) or 4 kg (dry) / kg

Fig. 4.2 : Material flow diagram of Sweet Sorghum Syrup-making pilot plant (60 kg syrup per batch)

shut down the plant due to lack of availability of sugarcane, as is the present norm in commercial gur-making plants.

f The scale of operation of this plant also appears to be very appropriate. Besides, since this plant can be operated almost throughout the year, it provides a steady source of employment for the labourers. Thus, it is quite possible that in certain cases, this may be the preferred choice of plant size for commercial operations.

With the successful development and operation of this pilot plant, one of the major objectives - that of stream-lining the process of producing syrup from sweet sorghum - was successfully met.

The other objective was to evaluate the techno-economic feasibility of using different sources of heat in this plant. They were (a) producer gas from the low density biomass gasification plant; (b) combustion of wet bagasse obtained directly from the 3-roller crusher, and (c) combustion of dry bagasse or sugarcane leaves. The results of operating the pilot plant on these furnaces are summarised below in Table 4.1 .

Table 4.1 : PERFORMANCE OF PILOT-SCALE SYRUP-MAKING FURNACES

	Gasifier-powered furnace	Model II	Model IIIa
1. Syrup produced, kg/batch	50-70	50-70	50-70
2. Fuel used	Sugarcane leaves (In gasifier)	Wet bagasse + sugarcane leaves	Wet bagasse + sugarcane leaves
3. Moisture content, % w/w (wet)	15%	Avg. 49.6	Avg. 40-48.6
4. Fuel consumption, kg (dry)/ kg syrup	6.26	4.62	4.26-5.67
5. Water boiling efficiency, %			
(a) Pan # 1	12.76	13.6-18.2	18.3-20.2
(b) Pan # 2	-	3.4-4.50	5.2-5.4
c Overall (Pan # 1 + Pan # 2)	12.76	17-22.7	23.5-25.4

The following interpretations can be made from the data presented in Table 4.1.

(a) The gasifier-powered furnace compares poorly with the other models, both in terms of its water boiling efficiency and in terms of the fuel consumed to produce 1 kg of syrup. This is because the char produced in the gasifier is not considered in these calculations.

(b) Among the other two models, Model IIIa shows slightly better performance, both in terms of the fuel consumption per kg of syrup and the water boiling efficiency. However, Model IIIa was slightly more laborious to operate. Poking of the bed was more frequent than in Model II.

(c) It is also seen that a trade-off is necessary between the desired fuel consumption and the moisture content of bagasse used in the furnace. Data from Model IIIa showed that the fuel consumption reduced significantly from 5.67 kg/kg syrup to 4.26 kg/kg syrup when the moisture content of bagasse used was 48.6% and 40% respectively. Thus, if maximum fuel economy is desired, then the bagasse should be as dry as possible (~ 5-10% moisture). However, if it is desired that the wet (~ 50% moisture) bagasse be used in the furnace, then extra fuel is needed to process the juice to make syrup. Thus, a practical perspective is to dry the bagasse to the extent necessary to achieve fuel self-sufficiency. For Model IIIa, the acceptable moisture content at which fuel self sufficiency can be reached in the present configuration is expected to be 30-40%. It was therefore concluded that Model IIIa operated on bagasse with 30-40% moisture was best suited to make syrup from sweet sorghum.

Some other salient features of syrup production using these furnaces are given below :

(a) During experiments with wet bagasse operation, it was seen that combustion could be sustained after a minimum of two hours of start up on dry fuel. Further, about six hours of operation were required for the furnace to approach steady-state conditions. This mode of operation of the furnace on wet bagasse is depicted in Fig. 4.3. It is seen that for the first two hours, the furnace has to be operated on dry fuel (moisture content < 35 %). For the next four-five hours, it can be operated on wet fuel (55 % moisture) with occasional doses of dry fuel to prevent quenching. The average moisture content during this phase of operation comes to 50 %. Only after the furnace has been in operation for more than six-seven hours can it be operated only on wet fuel.

This poses a severe constraint to the use of wet biomass combustors, especially for applications like the syrup or gur-making plant where the furnace is operated for eight-twelve hours in a day. Thus, it is felt that use of wet biomass may not be a viable proposition, unless other constraints like land or labour availability or costs drastically increase the drying cost of biomass to the extent that it offsets the increase in operating costs due to lower fuel efficiency on wet bagasse. For syrup production from sweet sorghum, use of 30-40% moisture bagasse is considered to be most suitable to approach fuel self sufficiency.

(b) Excellent quality of syrup was obtained on all the three furnaces. During operation on Model II and Model IIIa, a small quantity of fly-ash and dust particles (from the biomass) were present in the syrup. However, since the syrup was filtered before bottling, the final product did not contain any fly-ash or dust particles.

But this is not the case when gur is made. Filtration is not possible beyond the syrup stage, and so, the fly-ash and dust particles will remain in the final product. This is not a problem on the gasifier-furnace operation, since there is only a very negligible quantity of fly-ash in the flue gas. Thus, if gur is not to contain any fly-ash, the gasifier furnace system has a distinct advantage over the other two furnaces.

(c) It was found that control of the boiling rate and the temperature, especially near the end-point, was easily effected in all three furnaces. This belied the initial expectation that temperature control would be better in a gas-fired furnace as compared to a solid-fired one.

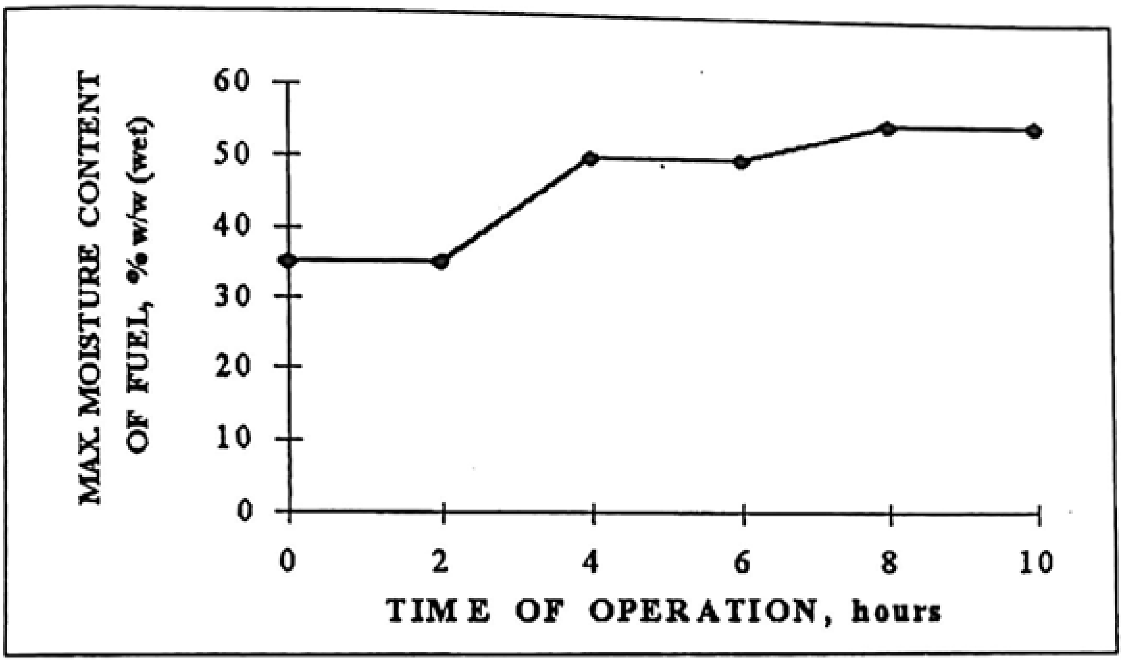


Fig. 4.3 : Mode of operation of the furnace on wet fuel

4.12 Economic Analysis

The economic analysis of the pilot plant pertains to comparing the cost of operating the plant on the gasifier-powered furnace and the direct combustion furnace. The equipment cost of the pilot plant was estimated as shown in Table 4.2.

Table 4.2 : EQUIPMENT COST OF PILOT PLANT

1. Equipments	Cost, Rs.
(a) Rectangular pan SS 304 (350 kg juice)	10,000
(b) Mesh filters (SS 304 meshes)	5,000
(c) Sharat # 2 crusher	15,000
(d) 10 HP electric motor (for crusher)	10,000
(e) Self priming pump with contact parts of SS 304 and 1 HP motor	12,000
(f) 1" NB PVC pipe 100' long	1,000
(g) SS vessels for storing syrup	10,000
(h) Shed (Roof with mud flooring)	25,000
(i) Misc	3,000
	1,00,000

This is the basic cost of the pilot plant, excluding the cost of the furnace. Depending on the choice of the furnace, the total cost of the pilot plant is as follows :

	Gasifier powered furnace	Direct combustion furnace
A. Equipment cost	1,00,000	1,00,000
B. Gasification System	9,50,000	-
C. Furnace	7,500	15,000
D. Combustion air blower (3 HP) with motor	-	20,000
E. Settling tank, civil construction etc.	5,000	5,000
	10,27,500	1,40,000

It is thus seen that the cost of the gasification system is by far the major cost component in the total system cost. This is because the low density biomass gasification system has to have a continuous feeding and ash removal system, unlike in the case of wood or rice husks gasifiers, where batch or intermittent feeding is admissable. Due to this, the cost of the conveyor and the control system required to regulate the biomass feeding and ash removal rates result in a very high initial cost of the system. This is clearly evident if the cost of a similar sized gasifier running on wood is compared (A wood based gasifier rated at 1440 MJ/h costs only Rs. 4,50,000[50]). However, since the objective was to utilise the bagasse generated on the gur-making plant, the cost of the leafy biomass gasifier developed at NARI was relevant.

These figures showed that there was no economic justification for using the low density biomass gasifier to produce syrup from sweet sorghum. Thus, further analysis was not carried out for the gasifier powered system.

The data on the operating costs for the direct combustion system were as follows :

1. The plant is assumed to operate like a regular industry for 300 days/year. Every day, since only one batch is made, a total of 300 batches are made every year.This is possible because sweet sorghum can be planted and harvested almost throughout the year.

2. The financing norms of nationalised banks for commercial enterprises is assumed to be as follows :

1. Loan amount	75 % of project cost
2. Equity	25 % of project cost
3. Interest rate	20 % p.a. on reducing capital
4. Repayment period	5 years

3. A minimum of 16% return of equity is assumed.

4. Three male and two female labourers are required per day. A male labourer is paid Rs. 50/day and a female labourer is paid Rs. 35/day.

5. About 20 kg/day of extra fuel is assumed to be required. The fuel cost is estimated at Re. 1/kg (dry).

6. The electricity consumption comes to 16 kWh/batch. The cost of electricity is Rs. 2.5/kWh.

7. No land or building costs are taken into account.

8. 60 kg syrup is assumed to be produced per batch. The sweet sorghum stalks requirement is ~ 1400 kg/batch. The cost of stripping the stalks comes to Rs. 250/T whole stalks.

The results of this analysis for a sweet sorghum stalk price of Rs. 400/T are given below in Table 4.3.

Table 4.3 : ECONOMICS OF SYRUP PRODUCTION IN THE PILOT PLANT

	Rs./year
A. **Fixed Cost**	
(i) Annual installment	21,000
(ii) Interest	13,000
(iii) Minimum return on equity	6,000
TOTAL	40,000
or **Rs. 135/batch**	
	Rs./batch
B. **Operating Cost**	
(I) Electricity	40
(ii) Labour	220
(iii) Extra fuel	20
(iv) Sweet sorghum stalks	560
(v) Stripping cost	350
	1190
C. Total Production Cost (A + B), Rs./batch	1325
Rs./kg	22
Assume 20 % wastage of syrup (in bottling, storage, handling etc.)	27

The production cost of syrup for different sweet sorghum stalk prices is shown in Fig. 4.4.

It is thus seen that the cost of producing syrup from sweet sorghum is Rs. 27/kg when the sweet sorghum stalks cost Rs. 400/T. This excludes the cost of packaging and marketing i.e. the cost of the bottles, advertising and marketing costs like wholesalers and retailers margins etc. Even when all these costs are considered, the syrup cost does not exceed Rs. 70/kg. During the course of this project, about 600 kg of syrup were test-marketed in Mumbai and Pune at a retail price of Rs. 80/kg. Thus, there was a clear net profit margin of Rs. 10/kg after all the taxes and other costs were taken into account.

This experience proved that there was considerable value addition to the sweet sorghum juice when it was processed to make syrup. Further, it is also seen that the pilot scale plant, by itself, is an economically attractive proposition. It can achieve an annual turnover of Rs. 14,40,000 can earn a net annual profit of ~ Rs. 1,80,000 on an investment of Rs. 1,40,000 if 300 batches of syrup (18 T) are made annually. The land requirement then comes to only about 6 ha/year with two harvests of sweet sorghum every year. Moreover, the plant operation is easy to manage, the logistics being simple-involving only one batch per day.

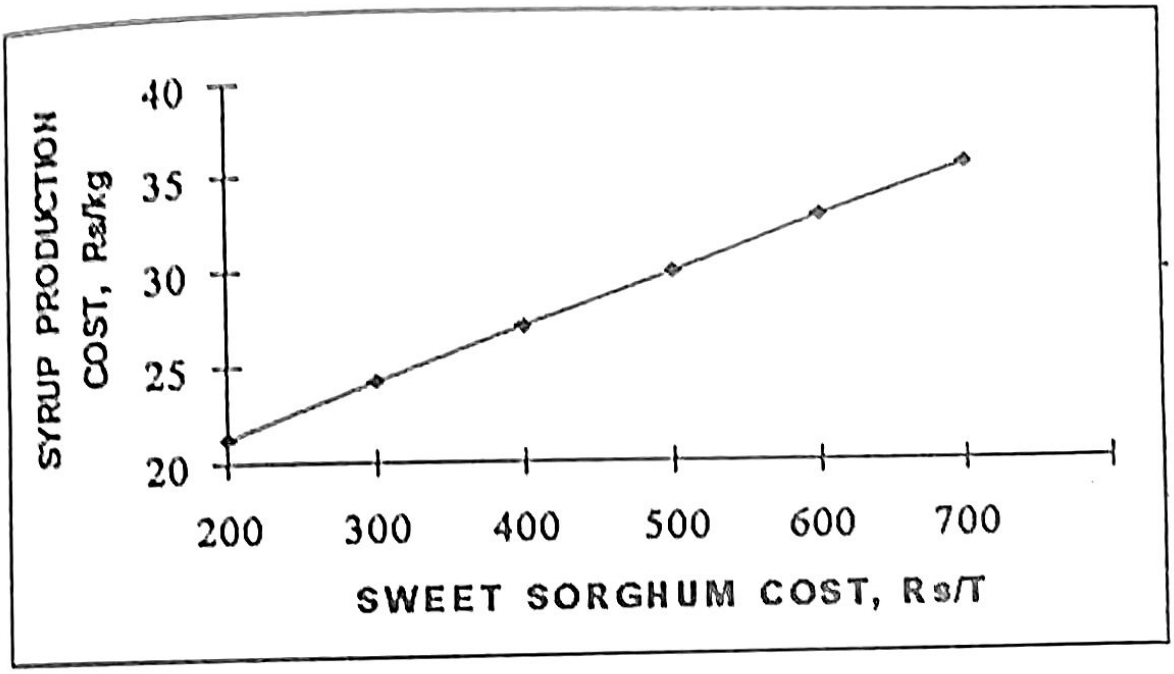


Fig. 4.4 : Syrup Production Cost vs Sweet Sorghum Cost

It is therefore felt that operation of this plant for one full year would further establish the validity of this limited exercise. This would then enable a detailed feasibility study to be carried out to establish whether this pilot scale plant itself may become the preferred choice of plant size for commercial operations for making syrup from sweet sorghum.

4.2 Gur Production from Sugarcane

Though not a part of the original project objectives, data were collected on different aspects of the gur making process both on a commercial scale and on a pilot scale operation. The most striking difference between them was in the processing of the juice. In the commercial-scale operation, indiscriminate quantities of various chemicals were used to obtain good colour (yellowish white) and crystallinity in gur. This was in marked contrast to the pilot scale operation where absolutely no chemicals were used. Even then, excellent quality of gur was produced in the pilot plant, both in terms of its taste and colour. This is seen in Fig. 4.5.

Preliminary exposure in the market revealed that the chemical-free gur commanded a premium price of Rs. 20-30/kg compared to Rs. 12-15/kg for the best 'Kolhapur' gur. Thus, it appears that production of chemical-free gur is an extremely attractive proposition. During this study, gur was made on a pilot scale of 50-70 kg/batch. So it may be worthwhile to evaluate and adapt this process so that chemical-free gur of excellent quality may be produced on a commercial scale. This will have a significant impact on the gur economy.

Data related to the gur-making process, both on the commercial and pilot plant scales, are presented below in Table 4.4.

Table 4.4 : DATA ON GUR PRODUCTION FROM SUGARCANE

	Commercial-scale	Pilot scale
1. Sugarcane stalks, kg	1270	438
2. Gur produced, kg	141	43.7
3. Gur yield, % w/w stalks	11.1	9.98
4. Juice extraction, % w/w stalks	61.9	48.9
5. Bagasse generated, kg (dry)	198	68.5
6. Bagasse, % stalks (dry weight basis)	15.6	15.64
7. Fuel required, kg (dry)	212	94
8. Batch time (Boiling time), min	135	158
9. Net Fuel Balance, (a) kg (dry)	- 14	- 25.5
(b) % of fuel consumed	- 6.6	- 27.1
10. Thermal efficiency, %	42	25

It is seen that the juice extraction was 61.9% in the commercial scale operation, whereas it was only ~48.9 % in the pilot scale operation. This was directly attributable to the quality of the crushers used. Both were 3-roller crushers; however one was powered by a 20 HP diesel engine whereas the other was powered by a 10 HP motor. This is also reflected in the gur recovery, which was 11.1% on stalk weight basis for the commercial operation and only 9.98% for the pilot scale operation.

Circular Gur-making furnace in the Pilot Plant at NARI

Gur produced in commercial-scale plant (C) and in the pilot-scale plant at NARI (P)

Fig. 4.5 : Gur Production in the Pilot Plant at NARI

The fuel balance was also found to be better in the bigger furnace. Only 14 kg (dry) of extra bagasse was required, as compared to nearly 26 kg of extra fuel in the pilot scale furnace. The thermal efficiency of the bigger furnace was also better at 42% than the pilot scale efficiency of 25%. Thus, it was clear that further improvements in the furnace efficiency would have to be carried out through experiments on the bigger furnace directly. This can be attempted in a sequel to this study.

Preliminary investigations into syrup making from sugarcane suggested that the process used in case of sweet sorghum syrup needs to be modified to produce good quality syrup from sugarcane. Nonetheless, it can be expected that syrup may provide more value addition and better returns to the producer than gur from sugarcane. This can be the subject of a separate study.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations arising out of the work done in this project is contained in this chapter. The major achievements of this project are also outlined here.

5.1 Conclusions

A. Salient Features of the Pilot Plant at NARI

1. A pilot scale plant producing 50-70 kg/batch syrup from sweet sorghum or gur from sugarcane was set up at NARI.

2. Excellent quality of syrup or gur is produced without using any chemicals at any stage of the manufacturing process. This was largely due to the development of an effective juice filteration system and development of optimum process parameters like the heating / boiling rate, cooling rate and the temperature at the 'end-point'. These were developed for both syrup and gur production from sweet sorghum and sugarcane respectively.

3. The pilot plant can be operated through-out the year, either on sweet sorghum alone or on a mix of sugarcane and sweet sorghum. This makes its economics very attractive even for the pilot scale operation.

B. Syrup Production from Sweet Sorghum

1. One of the major objectives was to develop a furnace suitable for producing syrup from sweet sorghum and which was (a) self sufficient in its fuel requirements (for boiling the juice) and/or (b) capable of using wet bagasse directly. Data showed that to achieve fuel self sufficiency for producing syrup from sweet sorghum, the fuel consumption should not exceed 4 kg (dry) or 9 kg (wet)/kg syrup. It was also established that fresh bagasse has a moisture content of 55% (w/w).

2. It was established that a rectangular pan was best suited to make syrup from sweet sorghum. So, rectangular furnaces were designed for this acitivity.

3. Two competing sources of heat for this pilot plant were evaluated for their fuel consumption and economic viability. They were (a) producer gas from a low density and leafy biomass gasification system and (b) a suitably designed direct combustion furnace for wet bagasse.

4. The gasifier-powered furnace was used mainly to optimize the various process parameters to produce excellent quality syrup from sweet sorghum and to evaluate its fuel consumption. Thus, it was found that a batch time of 4-5 hours was necessary to obtain good clarity in the syrup. The production processes and equipments were redesigned and arranged to reduce processing losses and to increase the syrup yield and labour productivity.

5. An effective juice filtration system was developed which obviated the need to allow the juice to

settle for about two hours. The juice is taken to the boiling pan directly after the crushing is over.

6. Water boiling tests showed that the overall thermal efficiency of the gasifier powered furnace came to 12.76 %. The gasification efficiency was 50% and the furnace efficiency was 25.52%. The temperature of the flue gas at the base of the chimney was 450-600 °C.

   The fuel consumption was about 6.26 kg (dry) sugarcane leaves / kg syrup which exceeded the target fuel consumption of 4 kg (dry) / kg syrup. Thus fuel self sufficiency could not be attained on the gasifier-furnace system.

7. The direct combustion furnace was designed based on the data generated on the gasifier furnace system. The major performance criteria were (a) that the furnace should be able to sustain wet bagasse (50% moisture) combustion and (b) that the fuel consumption should not exceed 4 kg (dry) /kg syrup.

8. Mechanisation of the fuel handling and ash removal operations were not found to be cost effective even at the commercial scale operation of the gur making furnaces (780 kg juice/batch). Though this was envisaged in the original objectives, mechanisation of the furnace was not incorporated in the final design. Both these operations were carried out manually in all the designs discussed in this report.

9. Three different models of the furnaces were designed and tested.

   The first model featured a separate combustion chamber, as it was thought that the hot refractory walls would facilitate combustion of wet fuel. A grate with provision for primary and secondary air was also provided in this chamber.

10. It was seen that this design could sustain combustion of 50% moisture bagasse. However, the combustion rate was only 60 kg / h (wet), which was very low. Water could not even be boiled at that rate. During dry fuel operation, there was considerable back pressure through the feeding port, and so it was concluded that this furnace was not suitable for making syrup.

11. In the next model (Model II), there was no separate combustion chamber. The pan was kept directly above the grate, but the other dimensions of the previous model were retained. This furnace had an additional pan which was used to sterilize the glass bottles used to package the syrup.

12. It was found that Model II could sustain combustion of bagasse containing an average 50% moisture. However, intermittent agitation and poking of the fuel bed were necessary. Moreover, the furnace could not be operated only on wet (55 % moisture) bagasse for more than 60-90 minutes. After that, some quantity of dry fuel had to be added to prevent quenching. Thus, the average moisture content of the fuel which could be combusted in this model came to 50%.

    There was no problem during operation with dry sugarcane leaves, and so, this model was suitable for both wet and dry fuel.

13. Water boiling tests showed that the overall system efficiency was 17-22.7% on sugarcane leaves, with the larger pan (containing juice) contributing 13.6-18.2% and the smaller pan (containing bottles to be sterilized) accounting for 3.4-4.5%. On bagasse, the overall efficiency was 18-20.5% with the contributions of the two pans being 15.5-17.6% and 2.5-2.9% respectively.

14. Data during syrup production from sweet sorghum showed that the fuel consumption was ~ 4.62 kg (dry)/kg syrup. Thus, this exceeded the target fuel consumption of 4 kg/kg syrup for fuel self-sufficiency. However, since only 2/3 of this furnace was used for syrup production and the remaining 1/3 for sterilizing bottles, the data on amount of water actually boiled of to that theoretically required to be boiled of to produce syrup were considered. Thus, it was seen that for fuel self-sufficiency, about 0.93 kg water/kg fuel consumed had to be boiled of, whereas about 1.01 kg of water were actually boiled of per kg of bagasse consumed. Thus, in this respect, Model II was considered to be self-sufficient in its fuel requirements.

15. However, there was still some blue smoke visible in the stack gases, especially on wet fuels. Further, there was some back-pressure from the feeding port due to the extreme turbulence created by the high velocity secondary air jets. These drawbacks in Model II were sought to be eliminated in Model III.

16. Model III incorporated the useful features of both the previous models. Thus, it had a rear arch extending to about 1/3 of the furnace opening in order to provide hot refractory surface for wet bagasse combustion. Like Model II, it also had two pans without a separate combustion chamber. The secondary air jets were placed deeper inside the furnace so that the back pressure through the feeding port was reduced.

Two versions of this model were tested, the only difference being the length of the rear arch. In Model IIIa, the arch covered 30% of the furnace opening, whereas in Model IIIb, it covered 55% of the furnace opening.

17. It was found that combustion of 47% moisture bagasse could be sustained, though intermittent poking and agitation of bed were found necessary. Occasionally, dry fuel had to be added to prevent quenching. Furhter, though there was a marginal increase in combustion stability in Model IIIb, it required about four hours to heat up and was not as suited as Model IIIa for dry fuel combustion. Thus, Model IIIa was preferred to Model IIIb for further studies.

18. Water boiling tests showed that the overall system efficiency of Model IIIa came to 23.5-25.6%, with the contributions of the two pans being 18.3-20.2% and 5.2-5.4% respectively. Thus, this had the highest thermal efficiency amongst the three models tested in this study.

19. Syrup production data showed that the fuel consumption depended on the moisture content of the fuel used. Thus, when fuel with an average moisture content of 48.6% was used, the fuel consumption came to 5.67 kg (dry)/kg syrup and 0.91 kg water removed/kg fuel consumed. However, when operating with 40% moisture content fuel, the corresponding figures were 4.26 kg (dry)/kg syrup and 1.17 kg water removed/kg fuel.

In both cases, the furnace is self-sufficient in terms of the fuel required to remove one kg water.

20. An economic analysis was then attempted for the pilot plant operation. The equipment cost of the plant came to Rs. 1,40,000, mainly because all the vessels and the boiling pan were made of stainless steel. The gasification plant cost was Rs. 9,50,000. Thus, it was seen that the use of the gasification plant was not justifiable on economic grounds.

21. The production cost of syrup from sweet sorghum was estimated for one batch operation per day and 300 batches per year. This pilot plant was treated like an industry and the financing pattern and interest rates considered for this analysis were those applicable for commercial enterprises.

Thus, equity was considered to be 25% of the project cost and the interest rate on the loan amount was taken to be 20% p.a. on reducing capital with a repayment period of 5 years.

22. This analysis revealed that the production cost of syrup in the pilot plant came to Rs. 27/kg. After considering the packaging, transportation, advertising and marketing costs, the net cost to the retailer was not expected to exceed Rs. 70/kg. During the course of this project, about 600 kg of syrup were sold in the retail market at Rs. 80/kg. Thus, a net profit of Rs. 10/kg was possible. For an annual production of 18,000 kg syrup, the annual turnover can be Rs. 14,40,000 and the net profit for the producer from the pilot plant operation can be in the range of Rs. 1,80,000/year. Thus, this analysis clearly showed that this pilot plant scale was commercially feasible. It is felt that under certain conditions, this pilot plant itself may be the preferred choice of plant size for commercial operations.

C. Gur Production from Sugarcane

1. Following the development of a rectangular wet bagasse combustor for syrup production, data were collected regarding the fuel consumption in a commercial gur-making plant located in Phaltan. This plant had a single-pan system processing about 780 kg juice/batch. The circular furnace had a grate and blower arrangement, due to which the batch time was reduced from 3-3½ hours on natural draught operation to 2-2½ hours. Thus, about one or two extra batches of gur could be made in a day.

2. The extent of black smoke in chimney reduced drastically and the fuel economy increased significantly due to the blower-grate arrangement. Data showed that about 212 kg (dry) bagasse were consumed to make 141 kg gur, whereas 198 kg (dry) bagasse was generated. Thus, there was a net shortfall of only 14 kg (dry). This was partly due to the poor quality of cane, which had been exposed to heavy rainfall just a week prior to harvest. Thus, the juice had a brix reading of only 18°.

3. The thermal efficiency of the furnace came to 42%, corresponding to a fuel consumption of 28.8% of dry bagasse on juice weight basis. This compares very favourably with those reported for other improved furnaces like the Annakapalle furnace (35-39%) and that of the Sindewahi furnace (46%). In fact, the thermal efficiency of 42% is only marginally less than the 43% reported for five pan systems used in the open pan sugar manufacture.

4. Further experiments were then carried out on a scaled-down version of the circular furnace at NARI. Water boiling tests showed that a maximum of 30% efficiency was reached after two hours of operation. Though this was significantly higher than 25.6% reached on the rectangular pan systems, it was considerably lower than the 42% levels reached on the commercial-scale furnace. The efficiency obtained on the commercial scale furnace could not be achieved on the smaller furnace. This was due to the adverse effect of the scaling-down process. In the commercial furnace, about 5.47 m^2 pan area was exposed to the hot flue gases as compared to only 1.33 m^2 in case of the pilot scale furnace per m^3 of the furnace volume.

5. Gur production data on the pilot scale showed that about 3.29 kg bagasse/kg gur was required in the first batch, but then, during the next batch, it reduced to 2.15 kg bagasse/kg gur. However, this was still higher than the requirement of 1.57 kg bagasse/kg gur to achieve fuel self-sufficiency. Thus, this experience showed that further improvements in the gur-making furnace will have to be carried out through experiments on the commercial-scale furnace itself.

6. However, a significant finding was that excellent quality of gur, both in taste and colour, was produced in this plant using the juice clarification system and the production protocol developed for making syrup from sweet sorghum. Thus, no chemicals were added at any stage of the gur making process, thereby clearly showing that addition of undesirable chemicals like 'hydros' can be avoided if suitable processing technologies are developed.

7. Some preliminary investigations into syrup production from sugarcane were also made. The same process as was used for making sweet sorghum syrup was also used to make syrup from sugarcane. It was found that both floating and settled impurities remained in the syrup, thereby signfying that the juice clarification and scum removal processes were not suitable for sugarcane juice. Moreover crystal formation and mold attack were observed after two three days and seven days respectively. Thus, these preliminary studies showed that the processes of making syrup from sweet sorghum and sugarcane were different and so a different processing technology needs to be developed to produce good quality syrup from sugarcane.

5.2 Achievements of the Project

The major achievements of this project can be summarised as follows :

1. A commercially viable pilot-scale plant for producing excellent quality syrup from sweet sorghum or gur from sugarcane was set up at NARI. About 50-70 kg of the syrup or gur is produced per batch.

2. No chemicals are added at any stage of the manufacturing process. Thus, an absolutely 'natural' product is obtained. This was due to the development of an effective processing technology.

3. A rectangular furnace capable of sustaining combustion of bagasse with an average moisture content of 50% was developed for this pilot plant. The furnace is rated at 1500 MJ/h. Fuel self-sufficiency was achieved for syrup production from sweet sorghum. However this was not possible in case of gur production from sugarcane.

4. Excellent quality of gur, both in taste and colour, was produced in this pilot plant without using any chemicals. It was seen that this 'chemical-free' gur can fetch a premium price as compared to 'ordinary' gur.

5. Preliminary investigations showed that the processing technology developed for sweet sorghum was not suitable to produce syrup from sugarcane. Thus, certain changes would be needed in the technology to produce good quality syrup from sugarcane.

5.3 Recommendations

1. It is recommended that the pilot scale plant developed in this study be operated throughout the year for producing syrup from sweet sorghum. A detailed techno-economic feasibility study of this size of the plant for full-fledged commercial operations can then be carried out. If found feasible, this plant can be made modular in nature, thereby helping to standardize the equipments used in the plant.

2. It was seen that fuel self-sufficiency with fresh (wet) bagasse may not be possible during gur

making from sugarcane. If wet bagasse is to be used, extra fuel will be needed which is not a viable proposition. Instead, operation on dry fuel may be a better alternative. It was seen that a blower and grate attachment in a commercial-scale gur making plant resulted in fuel self-sufficiency being attained on dry fuel operation. It is recommended that this aspect be investigated further and more studies be conducted on commercial gur making furnaces to establish this premise.

3. It is recommended that the processing technology for producing syrup from sugarcane be developed. It is felt that like in case of sweet sorghum , excellent quality syrup may provide more value addition and better returns to the producer than gur in case of sugarcane also.

REFERENCES

1. Dr. Jaswant Singh and Misra, S. R., "National Policy for and Industrial Potential of Jaggery and Khandsari Research and Industry in India", presented at the Third Coordination Committee Meeting of AICRP on PHS of Jaggery and Khandsari held at the Regional Sugarcane and Jaggery Research Station (MPKV), Kolhapur, July 17-18, 1996.

2. Singh, Kishan; Status Paper - Need for Research and Development of Jaggery, Khandsari and Brown Sugar Industry of India; in Proceedings National Seminar-Cum-Group Discussion on Jaggery Manufacture and Storage, December 18-19, 1985 published by Indian Institute of Sugarcane Research, Lucknow, 1987.

3. Bangali Baboo; Proceedings National Seminar-Cum-Group Discussion on Jaggery Manufacture and Storage, December 18-19, 1985 published by Indian Institute of Sugarcane Research, Lucknow, 1987.

4. Rajvanshi, A. K., De, T. K., Jorapur, R. M. and Nimbkar N., Jaggery and Syrup from Sweet Sorghum; Publication No. NARI-GUR (1993), published by Nimbkar Agricultural Research Institute, Phaltan. March 1993.

5. "Ethanol Production from Sweet Sorghum", Final Project Report submitted to Ministry of Non-conventional Energy Sources (MNES), New Delhi, 1991. Prepared by Nimbkar Agricultural Research Institute, Phaltan.

6. Rajvanshi, A. K., De, T. K. and Jorapur, R. M., Development and propagation of efficient gur making technology from sugarcane and sorghum - Phase II, Final Project Report submitted to Council for Advancement of People's Action and Rural Technology (CAPART), New Delhi. Prepared by Nimbkar Agricultural Research Institute, Phaltan. November 1992.

7. Personal Communication, Central Food Technological Research Institute, Mysore and ITALAB Pvt. Ltd. Mumbai.

8. The Wealth of India : Raw Materials Vol I, published by Council of Scientific and Industrial Research, New Delhi, 1948.

9. Use of Low Density Biomass Gasification System for Process Heat Applications in Metallurgical and Agro-based Industry; Final Project Report submitted to The Rockefeller Foundation, New York, U.S.A. prepared by Nimbkar Agricultural Research Institute, Phaltan. January 1996.

10. Report of Fourth Technical Seminar on The Open Pan Sugar Manufacture; September 24-26, 1966; P.R.A.I. Publication No. 350, published by Planning Research and Action Institute, Planning Dept., Lucknow, February 1968.

11. Chapter VI : Juice and Molasses Boiling; P.R.A.I. Publication No. 350, published by Planning Research and Action Institute, Planning Dept., Lucknow, February 1968.

12. Personal Communication, Indian Institute of Sugarcane Research, Lucknow. 1996.

13. Baboo, Bangali; Bibliography of Researches on Jaggery (Gur) in India (1909-1988); Technical Bulletin No. 28, published by Indian Institute of Sugarcane Research (IISR), Lucknow, 1990.

14. Dr. Jaswant Singh, "Welcome Address and Report on Projects' Activities", presented at the Third Coordination Committee Meeting of AICRP on PHS of Jaggery and Khandsari held at the Regional Sugarcane and Jaggery Research Station (MPKV), Kolhapur, July 17-18, 1996.

15. Jaggery (Gur) Research at Annakapalle - AICRP on Processing, Handling and Storage of Jaggery and Khandsari, published by the Regional Agricultural Research Station, Andhra Pradesh Agricultural University, Annakapalle.

16. Meena Nigam, V. K. Madan and Bangali Baboo; "Effect of Coloured Non-sugars in juice on Jaggery Manufacture and Storage"; Proceedings National Seminar-Cum-Group Discussion on Jaggery Manufacture and Storage, Dec. 18-19, 1985. Compiled by Bangali Baboo, Indian Institute of Sugarcane Research, Lucknow. pp. 105-107.

17. Grover, P. D. and Baveja, K. K., Personal Communication, Indian Institute of Technology, New Delhi. June 1990.

18. C. Gopala Rao, Singh, C. P. and Bhatti, M. S.; "Effect of Air-fuel ratio on Bagasse fired Boiler Performance", Energy Management Vol. 17/1, March 1993. pp. 29-38.

19. Claar II. P.W., Wahby, M.F., and Buchele, W.F., " Development and Evaluation of a Biomass - Fuelled Furnace "; Energy in Agriculture, 6 (1987) 195-213.

20. Chapter 12 : Furnaces for Wood Refuse and Bagasse. In Combustion Engineering. Ed. Otto de Lorenzl, M. E., Published by Combustion Engineering - Superheater Inc. New York. 1949 p. 12.27-12.30.

21. Ed. J. Kenneth Salisbury, Section 2. Combustion and Fuels, in Kent's Mechanical Engineers Handbook; Power Volume; XII edition, Wiley Engineering Handbook Series; published by John Wiley and Sons, inc. , New York.

22. Dr. Samir Sarkar, Chapter 9 : Combustion Appliances, in Fuels and Combustion II Edition, published by Orient Longman Ltd., Hyderabad, 1994.

23. Personal Communication, ISGEC John Thompson, 6, Community Centre, Friends Colony, Post Box 7307, New Delhi-110 065.

24. Personal Communication, Batliboi and Company Ltd., Apeejay House, P. Box 479, Dr. V. B. Gandhi Marg, Fort, Bombay-400 001.

25. Personal Communication, Kalpana Boilers, 18, Kailash Park, Chirag Nagar, L.B.S. Marg, Ghatkopar (W), Bombay-400 086.

26. Personal Communication, Thermax Ltd., Pune.

27. Personal Communication, Sahyadhri Sales Corporation (Representative of TEXMACO, Calcutta), Jevan Darshan, Laxmi Road, PUNE-411 030.

28. Personal Communication, Laxmi Boilers, 12-A, Chandivali Industrial Estate, Saki Vihar Road, Bombay-400 072.

29. Personal Communication, Industrial Boilers Ltd., 701-C, Poonam Chambers, Dr. Annie Besant Road, Worli, Bombay-400 018.

30. Personal Communication, Double Ace Engineers, 1/3, Siddhartha Nagar III, Next to Siddhi Vinayak Temple, S. V. Road, Goregaon (West), Bombay-400 104.

31. Rajvanshi, A.K. and Jorapur, R.M., "Design and Development of 10-15 kW Gasifier running on Loose Sugarcane Leaves "; Final Project Report submitted to the Ministry of Non-conventional Energy Sources (MNES), New Delhi, prepared by Nimbkar Agricultural Research Institute (NARI), Phaltan . 1994.

32. Tariq, A. S., Reupke, P. and Sarwar, G.; Biomass Combustion Systems - A Guide for Monitoring and Efficient Operation; published by Natural Resources Institute (NRI), U.K. 1994.

33. Dr. Samir Sarkar; Chapter 3 : Solid Fuels; in Fuels and Combustion II Edition, published by Orient Longman Ltd., Hyderabad, 1994. pp. 30-87.

34. Reupke, P. and Tariq, A. S., Biomass-fuelled Indirect Air Heater for Agro-processing Industries : Design Approach; published by Natural Resources Institute (NRI), U.K. 1994.

35. Susanto, H. and Argasetya, G. H., "Design of a Small Incinerator for Solid Municipal Wastes", ASEAN Workshop on Thermal Conversion of Biomass, September 1988. pp. 258-267.

36. Ed. Perry, R. H. And Chilton, C. H., Chemical Engineers Handbook. Fifth Edition, published by McGraw-Hill Kogakusha Ltd. Tokyo, 1973.

37. Ed. Spiers, H. M., Technical Data on Fuel, published by The British National Committee, World Power Conference, London, 1962.

38. Personal Communication, Shri. Balasaheb Kadam, Agri-Tec Enterprises, Phaltan. 1996

39. Srivastava, N.S.L. and Agarwal, B. D., "Research and Development in Sugarcane for Jaggery Industry"; Proceedings National Seminar-Cum-Group Discussion on Jaggery Manufacture and Storage, Dec. 18-19, 1985. Compiled by Bangali Baboo, Indian Institute of Sugarcane Research, Lucknow, 1987.

40. Pandit, S.N., "Some Thoughts on Khandsari Sugar and Jaggery-making - Ways to Better Efficiency; Proceedings National Seminar-Cum-Group Discussion on Jaggery Manufacture and Storage, Dec. 18-19, 1985. Compiled by Bangali Baboo, Indian Institute of Sugarcane Research, Lucknow, 1987.

41. Andhare, K. N., "Bagasse Boon to Sugar Mills for growth of Paper Industry in India", Technical Papers : 42 Annual Convention Part I, The Deccan Sugar Technologists' Association (India), p B-7, 1992.

42. Bisht, B. S. and Alam, A., "Agro-processing Model for Jaggery Production and Sensitivity of Cost Factors", Proceedings National Seminar-Cum-Group Discussion on Jaggery Manufacture and Storage, Dec. 18-19, 1985. Compiled by Bangali Baboo, Indian Institute of Sugarcane Research, Lucknow, 1987.

43. Development of Technology for Producing Jaggery and Syrup from Sweet Sorghum; Annual Progress Report sent to the Indian Council of Agricultural Research, New Delhi prepared by Nimbkar Agricultural Research Institute, Phaltan. April 1996.

44. Pratt, A. D., Chapter XIII : Heat Balance, in Principles of Combustion in the Steam Boiler Furnace, published by The Babcock and Wilcox Co., New York, 1920.

45. Ed Baumeister, Th and Marks, L.S., Standard Handbook for Mechanical Engineers VII Edition, published by McGraw-Hill Book Co., New York. 1967.

46. Agarwal, M. L., Dua, S.R., Dubey, V. And Dixit, G. S., "A Resume of Work Done on Gur Manufacture and Storage"; Proceedings National Seminar-Cum-Group Discussion on Jaggery Manufacture and Storage, Dec. 18-19, 1985. Compiled by Bangali Baboo, Indian Institute of Sugarcane Research, Lucknow, 1987.

47. Personal Communication Dr. Jaswant Singh. 1996.

48. Patil, J.R., Wandre, S.S. and Gojare, D.G., " Kakavi Quality in Relation to Sterilization and Preservatives "; Proceedings National Seminar-Cum-Group Discussion on Jaggery Manufacture and Storage, Dec. 18-19, 1985. Compiled by Bangali Baboo, Indian Institute of Sugarcane Research, Lucknow, 1987.

49. Personal Communication, Four Eyes Research (P) Ltd., 798, Bhandarkar Road, Pune 4. 1996.

50. Personal Communication, Cosmo Powertek. Pvt. Ltd., Raipur. 1996.