



VALUE ADDED WHEAT CRC FINAL REPORT

Project: 2.1.6
GRDC Project CWQ13

Replacement of Chlorination Treatment for Cake Flours

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Ken Quail
Chuck Walker
Kirsty Germaine

BRI Australia



Baking Services & Training

April 2004

**Presented to
Allied Mills**

April 2004

Executive Summary

It is considered desirable to find an alternative to chlorine for treating flour destined to be used in cakes, particularly high-ratio formulas. This project has considered a number of alternatives.

Three major approaches were applied.

- 1 The effect of flour variety and quality,
- 2 Adding various ingredients, and
- 3 Treating the flour in various ways.

a) Low protein, low ash, fine particle size flours from soft wheats with high swelling power were identified as most desirable.

b) Wheat starch and guar gum were helpful, and an effective cake-emulsifier system was essential. Changes in eggs, milk, and sugar types were of little help, as was the addition of enzymes.

c) Various oxidizing and reducing agents and flour treatments, including annealing the starch, were of relatively little value except for heat-treating the flour or added starch.

d) The most successful approach was demonstrated when a 'proof-of-principle' apparatus was constructed to fluidize non-predried flour with heated air at temperatures considerably above prior conventional approaches. The best results occurred when flour was fluidized in air at about 280 °C for about two (2) minutes.

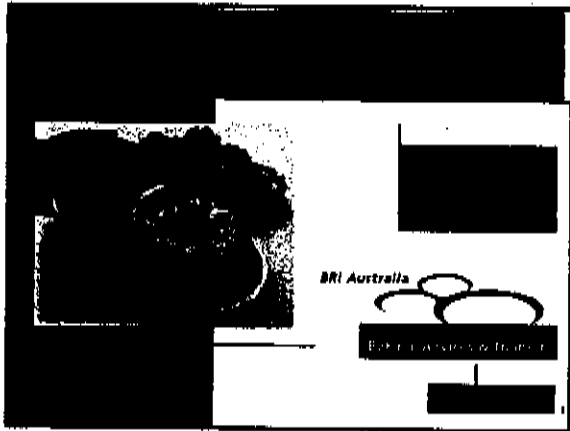
e) Higher temperatures and shorter times may be possible, but this was the limit of operation for the prototype equipment.

f) Final flour temperatures at about 150 - 160 °C appeared to be best, with dextrinization (viscosity loss) and color darkening occurring by 170 °C.

g) The RVA appears to be useful to monitor the changes in starch properties caused by the heat treatment, and is more rapid and lower cost than DSC techniques.

Conclusions: It is possible to heat-treat flour for high-ratio cakes in a short time without predrying the flour. Heavier cake formulas appeared to benefit from the treatment as well as did the 'sponge' type.

Recommendations: A larger scale, more instrumented and controllable fluidizer should be constructed to (a) optimize the treatment conditions, (b) determine the maximum temperature and minimum time limits, (c) to produce sufficient quantities of flour for larger scale tests on a wide range of cake formulas, and (d) to provide engineering data for scale-up to a commercial size operation.



Overview

- Project Objectives
- Summary of Research
- Current Projects
- Significant Outcomes

Project Objectives

- Original Aim
 - To find an effective, cost efficient strategy to replace flour chlorination as a treatment for cake flours.
- Chlorination
 - Enables the addition of higher sugar levels in high-ratio cakes
 - Modifies starch, lipids & proteins
 - Forms more stable cakes less prone to collapse

Project Objectives *continued*

- Why remove chlorine?
 - Chlorine gas is a dangerous chemical
 - Already banned in most European countries & the UK
- The main flour treatment currently used in the UK & in Japan is heat treatment.
- Current heat treatment methods typically use pre-dried flour and treat to a flour temperature of 135-145°C, for 1/2 hr.

Summary of Research

- 3 main research streams
 - Effect of flour quality/variety
 - Ingredient Addition
 - Flour Treatment
- Flour Quality/Variety
 - Low protein/ Low ash
 - Fine particle size
 - High starch swelling (Rosella)

Summary of Research

- Ingredient Addition
 - Emulsifiers
 - Gums/Starches
 - Egg Types/Powders
 - Modified Milk Powders
 - Enzymes
 - Sugar Types
- Wheat starch & guar gum were the most effective ingredient combination.

Summary of Research

- Flour Treatment
 - Oxidising/Reducing Agents
 - pH variations
 - Ozone
 - Pressurised CO₂ & O₂ treatment
 - Heat Treatment of starch & flour
- Heat treatment was the most effective treatment of both flour and starch.
- Showed that the RVA can be used to measure starch changes during heat treatment.

Current Projects

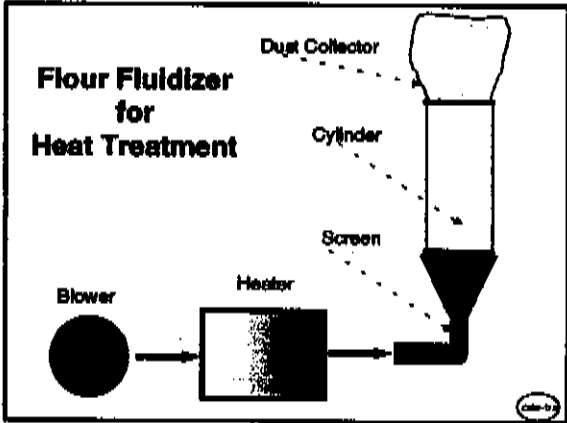
- Starch Annealing
- Fluidised Heat Treatment
 - Effect of Moisture Content
 - Effect of Flour Quality
 - Maximum Temperatures
 - Effect of Particle Size
 - Standard Heat vs Fluidised

Starch Annealing

- Using RVA Analysis 3-way RSM design:
 - Holding time (20-60min)
 - Temperature (40-60°C)
 - Water level (1:3 to 1:12)
- Optimally treated annealed starch performed similar to commercial wheat starch when added at 50% flour substitution.

Fluidised Heat Treatment

- Initial heat treatment work used a standard heating method (170°C, 30min, stationary batch process)
- Optimal flour temperatures ranged from 125-135°C.
- The fluidised system was created to optimise the surface area of air to flour with the aim of decreasing the required flour treatment time.



Fluidised Heat Treatment

- Initial Fluidised testing used:
 - Dried flour (-4% moisture)
 - Aged fine particle sized flour
 - Set Air Temperatures 210-270°C
 - Times of 6-14 minutes
 - Flours re-humidified before baking
- Achieved cake scores which were 90% of chlorinated control.

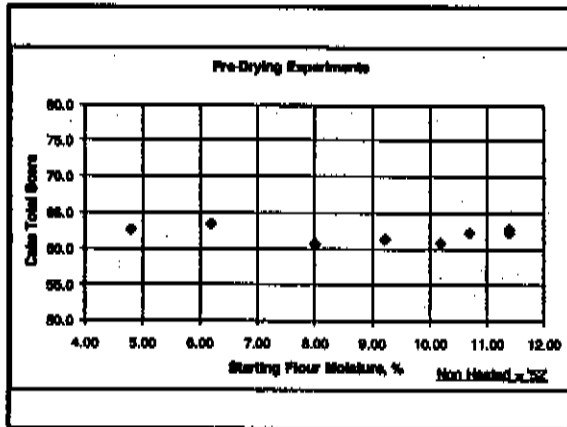
Effect of Initial Flour Moisture

- Traditional heat treatment methods require a drying step before heat treatment to prevent "balling-up" of flour.
- Investigated whether pre-drying was required before fluidised heat treatment.
- Used aged fine flour (J5314) one non-dried with a 12% moisture content, and the other dried to 4% (both heated at 270°C for 6 minutes)

95% Control Score

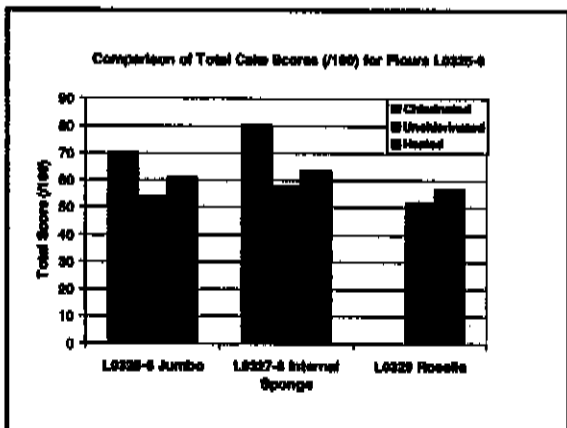
Effect of Initial Flour Moisture

- Study indicated that pre-drying was not required.
- Obtained fresh flour samples for further trials.
- Pre-dried flours in fluidiser to moisture contents ranging from non-dried (11.4% moisture) to 4.8% moisture.
- Flours were heat treated at 270°C for 5min, re-humidified and baked.



Effect of Flour Quality

- New Flours obtained from Allied Mills:
 - 2 Chlorinated & Unchlorinated pairs
 - Jumbo brand
 - Internal Sponge
 - Unchlorinated Rosella Flour (Udon)
- With heat all unchlorinated flours produced cakes of good external appearance and shape.
- Internal structure and volume were not as good as the aged fine particle flour.



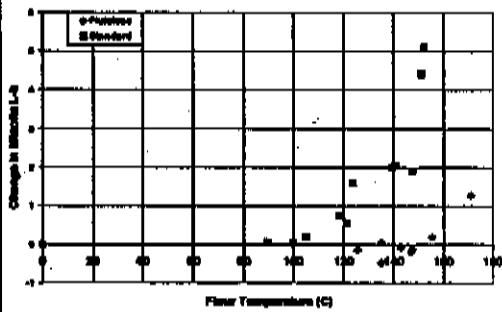
Maximum Treatment Temp

- Aim:
 - To determine the maximum air temperature which could be used in the fluidised system before causing flour browning.
- Maximum Set Temperature?
 - Currently 320°C
 - Time 1.5min = Flour Temp 135 °C
- Current Maximum Temperature only limited by the equipment.



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Flour Temperature vs Change in Alveolus L6 for Fluid vs Standard Heat

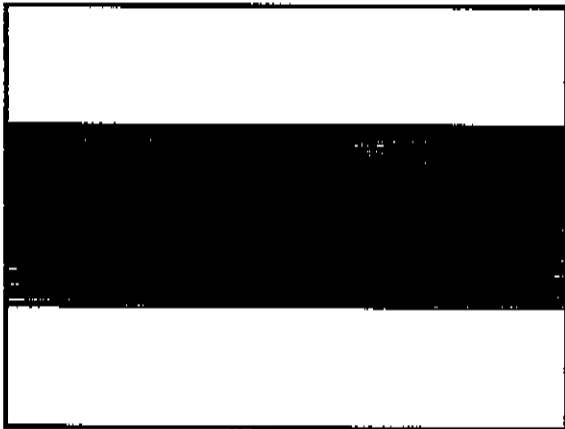


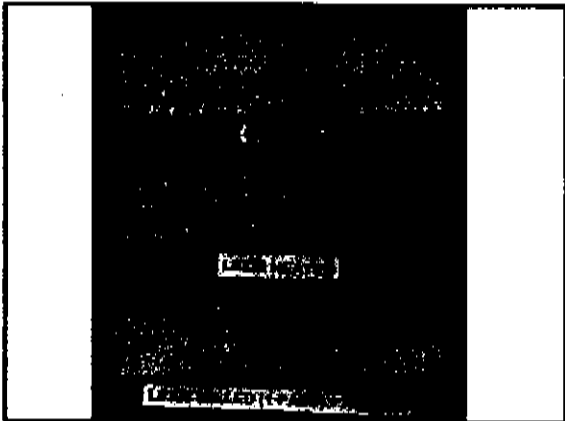
Effect of Particle Size

- Previous air classification study indicated that flours with a fine particle size performed better with heat treatment.
- Pin-milled & heat treated the best performing fresh flour (Internal Sponge)
- The pin-milled flour achieved a 113% improvement in cake score compared to the non-pin-milled flour.



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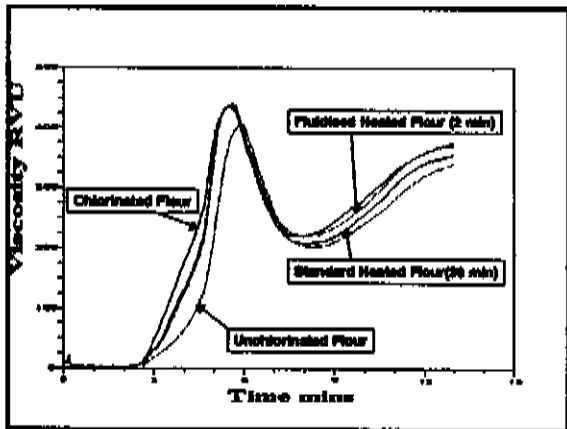




Standard vs Fluidised Heat

- Pin-milled flour was heat treated using:
 - (a) Standard Heat
 - pre-dried flour
 - 170°C set temp, 30 minutes
 - (b) Fluidised Heat
 - non-dried flour
 - 310°C set temp, 2 minutes
- Results indicated that both methods produced cakes of equivalent quality and RVA properties.

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Significant Outcomes

- Highest cake scores were achieved with good flour quality, ageing, a fine particle size and fluidised heat.
- Fluidised Heat treatment using high temperature/short times produces cakes of equivalent quality to standard long time heat treatment processes.
- Pre-drying of flour is not required with the fluidised system.
- RVA Analysis can be used to measure the effectiveness of flour heat treatment.

Fluidized Bed Heat Treatment for Chlorine Free Cake Flour

Report by
BRI-Australia
22 April 2004



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Principle Intended:

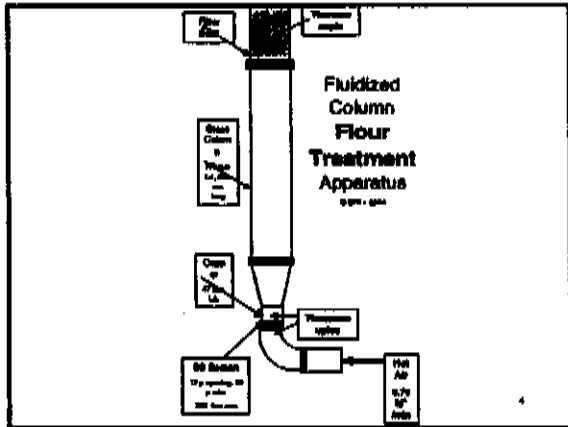
- Surround particles with hot air
- Dry & heat treat simultaneously
- Permit very high air temperatures
- Reduce time required
- Reduce damage to flour

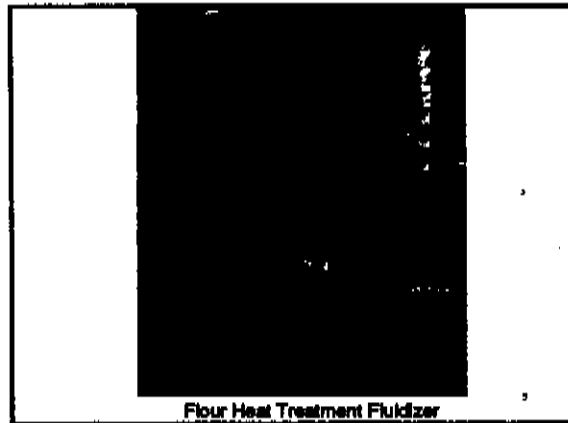
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Prototype Equipment

- Pressure air supply
- Air heater with temperature controller
- Fluidizing column with quick connect
 - fluidizing section
 - de-entrainment section
- Air & flour temperature monitoring
- Filter sock

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Flour Heat Treatment Fluidizer

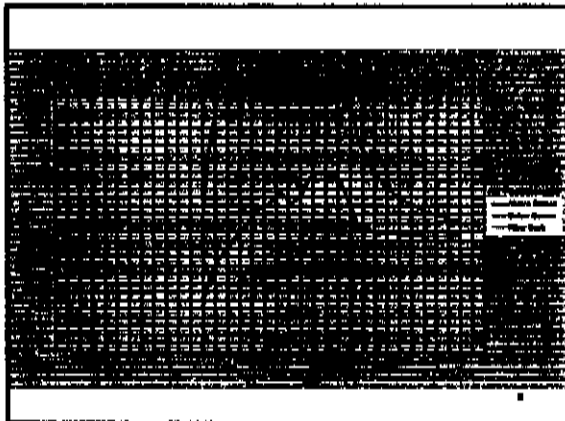


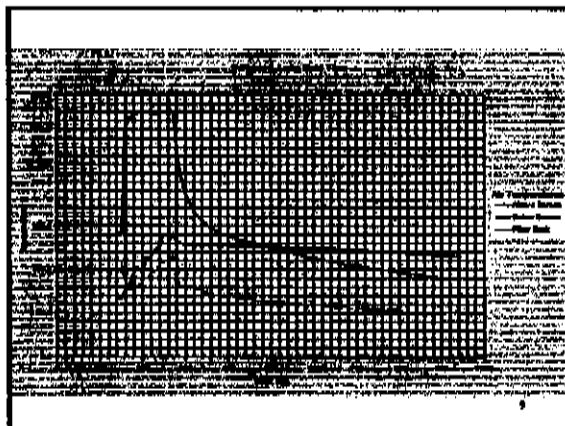
Connection Details - Flour Heat Treatment Fluidizer

Fluidized Heat Treatment

- Supply air to column ~ 285 °C
- Preheat column to ~ 260 °C, disconnect
- Add 300 g flour, NOT pre-dried
- Re-connect column to air & fluidize
- Treat 2-minutes, disconnect air supply
- Flour temperature ~ 140 - 150 °C
- Remove & rehydrate flour ↴

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Observations/Needs

- Apparently not necessary to pre-dry flour
- Moisture removal or addition important?
- Initial & final flour temperatures important
- Holding time or post-cooling important?
- Need to define upper temperature limits
- Need larger difference in the two sections
- Control all temperatures & times accurately
- Improve add/remove flour methods
- Improve cleaning procedures
- Do a cost-energy efficiency study

Safety Note

- Safe from dust explosions below 440 °C ?
- Avoid point ignition sources
- Design heat source carefully & dust free
- Conducted a literature search; but
- Still need to have experts study the system.

Sponge Cake

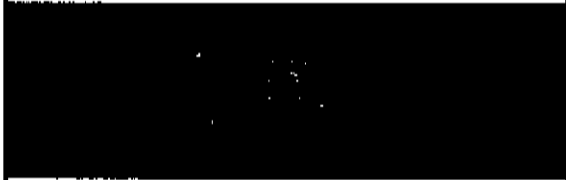


Other Cake Formulas?

- Most work previously w/ Sponges
- Many other cake types are important
- Some at much higher sugar levels (whereas Europeans use lower ratios)
- So tried treated flour on other types also

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Madeira Cake



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Rich Choc. Cake

- CHLORINATED FLOUR
- FLUIDISED HEATED FLOUR
- UNCHLORINATED FLOUR

Fluidization Process Advantages

- No pre-drying required
- Potential for reducing times even more
- Possible 'flow-through' continuous system?
 - 150 M long conveyor tube, or
 - hold-time, or
 - 'spray dryer' configuration
- No flour browning, better color

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Statement of the Situation

- Present equipment for 'proof of principle'
- Have not exhausted 'tweaking' studies
 - physical / mixing ~ speed, time, whip design
 - minor formula - water, emulsifier, leavening
 - baking ~ time, temperature
on batter density, viscosity, bubble size...
- Wider range of formula types & applicability
- Cannot do without lots of consistent flour
- Therefor, our recommendations:

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Recommendations

- 1) Do a cost-benefit ratio study
- 2) Design & construct a pilot unit
- 3) Obtain data for scale-up, and samples for larger scale bake tests
- 4) Verify #1

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In Conclusion

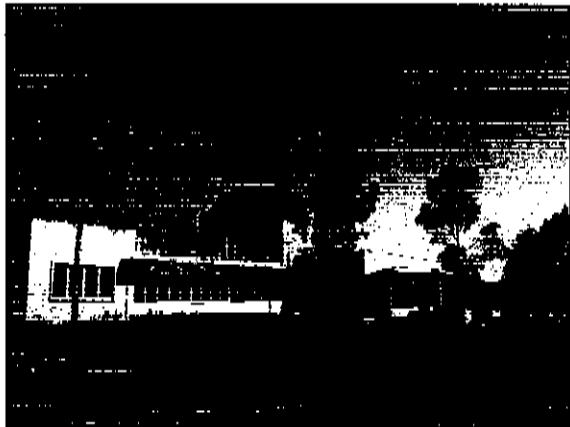
- This process has the potential to save money, space, and time
- It is worth studying further
 - even if only to have data, anticipating
 - when Cl2 is finally banned.
- BRI is able to do this project and recommends that it be continued.

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Thank You!

by:
Ken Quail
Kirsty Germaine
Chuck Walker





**Generalized Operation
And Some Observations
On the
Fluidized Bed Flour Heating Apparatus**

The following are the general operating conditions and procedures for the fluidized bed heat treatment of flour, based upon the apparatus in use at the time. This information may be of value for future scale-up and design of a pilot-scale fluidized bed heat treatment apparatus. The good and bad features are mentioned, indicating some places where additional engineering or research needs to be conducted. The following list is arranged generally in operation order.

1) Basic Principles:

By fluidizing flour in a hot rapidly moving air stream, each particle is surrounded by air that quickly strips its water and raises its temperature. Because the flour is drying out, the flour particle temperatures do not get as high as the air supply, so the drying and heat treating steps can be combined into a very rapid single-stage operation. This is analogous to the spray-drying process used for milk and many other heat-labile materials.

2) General Operation:

- 3) Preheat the air supply chamber to 310 °C. (The initial design did not anticipate operating the apparatus at more than 200 °C.) We were operating at the upper limits of the equipment at 310 °C. Some equipment damage was apparent at this temperature. Air temperature was controlled where it discharged from the heater box.
- 4) Indications are that even higher temperatures for even shorter times should be investigated, but are not practical without modifying or replacing the present equipment.
- 5) Two portable compressors supplied air at about 175 KPa to the electric heaters. The major pressure drop apparently occurred at the 'quick connect' where the air entered the heater box. No accurate airflow measurements were possible.
- 6) The column was preheated until the air in the empty entrainment section above the screen was 260 °C.
- 7) The column was quickly disconnected from the heater and 300 g of flour was added. The flour was not pre-dried. The room temperature flour typically warmed-up to between 40 °C & 50 °C (although a few reached 70 – 80 °C) during the approximately 1.5 minutes required to assemble the apparatus & connect it to the hot air supply, as indicated by the Type-K thermocouple mounted near the center of the fluidizing section.
- 8) Note that it is apparently not necessary to pre-dry flour treated by this approach because the large quantity of air carries away the moisture emerging from the flour rather than permitting it to make 'balls' and/or contributing to partial pre-gelatinization as can occur in a fixed or agitated deep bed system. The flour being used for these trials had a moisture content of 11.4 %, which may be somewhat lower than flour fresh off the mill in many occasions.
- 9) Initial flour temperature affects final flour temperature and must be accurately monitored and controlled for consistent results.

- 10) The air temperature just below the fluidizing screen typically stabilized at about 284 °C during the actual run and should be the temperature understood as the basis for future research rather than the 310 °C air supply set-point. Although the system was partially insulated, considerable heat was lost during operation, and it was noted that the drop was apparently linear with the air temperature set point.
- 11) The air appeared to fluidize the sample well, as indicated by an observation section near the base of the glass column. Some flour did go to the top of the column and lodge at the filter sock support & connect ring so it received less treatment than the rest of the sample.
- 12) The change in cross-sectional area from fluidizing to de-entraining sections was approximately a 1:4 ratio. This needs to be increased because of the large range in cake flour particle size.
- 13) The column was agitated continually by vibrating the entire column at 50 Hz. Fine flour tended to hang up on the walls without the vibration. Isolated wheat starch, even finer, neither fluidized nor de-entrained well, and also went through the filter sock.
- 14) Air typically discharged from the filter sock at more than 100 °C. This point is the typical control point for large fluidized bed dryers, but was too variable in this one.
- 15) The temperature of the fluidized flour-air mixture in the entraining section was typically around 190 C shortly before finishing. This is also a potential control point for future studies.
- 16) Two-minutes after starting, the connection was broken and the flour column collapsed back down into the fluidizing section where its temperature typically ran between 150 °C and 160 °C for the best products produced in this series.
- 17) The filter sock was removed, the treatment apparatus lifted & inverted, and the flour discharged into a rectangular aluminum pan where it cooled relatively rapidly to near room temperature. It typically took about 1.5 minutes from air disconnect 'til the flour was completely discharged.
- 18) Placing flour into the system and removing it was a major hurdle with the present 'quick & dirty' design. This must be changed in a larger scale more controlled test apparatus.
- 19) Reproducibility was not as good as desired. More temperature instrumentation and controls are necessary, as well as a way to properly monitor the actual airflow to the system.
- 20) The time the flour remained in the column after the fluidizing air was disconnected did not appear to have a major influence on the baking quality, as one sample was left in for 11 minutes after the air was disconnected. The flour temperature started at 131 °C (unusually low) when the air was first disconnected and was still 115 °C at that time it was removed. The cake volume and score were slightly higher than a sample of the same flour dumped after the usual 1.5 minutes rest time. (Note: higher cake scores were attained with higher flour temperatures, this is an illustration of a longer holding time only.)
- 21) This possible influence of holding time will need to be studied further to determine whether or not a controlled holding time or a cooler needs to be included in a larger-scale design.
- 22) The column was briefly cleaned between runs using a vacuum cleaner, then reheated before the next run. No obvious generalized flour discoloration occurred when heating by this process (as opposed by the traditional oven treatment) but occasionally a few browned particles did appear, apparently the result of some flour remaining stuck someplace in the system for more than one cycle.

23) Conclusions and Recommendations:

- 24) The obvious next step is to construct a more automated, better instrumented, and satisfactorily controllable pilot-scale model heating fluidizer to obtain more engineering data so that a realistic estimate can be made for a production scale plant and to further identify the optimum times, temperatures, & holding details needed to produce the best quality product. This is also necessary in order to make sufficient quantity flour that it can be tested on more formulas and styles of cakes by several bakers, determining if systematic changes need to be made in the water or emulsifier levels or other formula changes. E.g., is re-hydration really necessary, and if so, how might it best be done.
- 25) Ultimately, the system might be made continuous or automated rapid batching, but a pilot scale unit probably still needs to be a batch design.
- 26) One major obstacle may be in finding a food grade silicone free heat proof sealant.
- 27) A better and simpler cleaning procedure is needed, as well as a simpler charge/discharge cycle method.
- 28) A cost and energy efficiency comparison should be made (estimated) between the traditional slow (30 min.) relatively low temperature treatment method using pre-drying with the proposed single-stage high-temperature short-time aerated method before proceeding with the project and actually constructing a pilot scale unit.
- 29) A final note must be added regarding safety in a fluidized flour system. Flour or other organic dust is notoriously explosive when suspended at certain solids/air ratios. A literature search was done to check this situation before we operated the equipment above 200 °C. Dust explosions are not caused by a slow, generalized heating of the dust, but rather by point sources such as sparks or flames where the ignition temperature is exceeded. For flour in air, the ignition point has been identified as 440 °C. The maximum temperature in which we have operated to date exposed air to a maximum of about 295 °C. The design must very carefully consider these features however to be sure that the fluidized suspension can never approach the ignition temperature nor can errant flour dust be permitted to enter the heat source, which may well be gas burners, and abundant safety features must be incorporated.
See e-mail from Dan Brabec that is included in this report.
- 30) BRI-Australia is willing and able to continue with the design, construction, and operation of a pilot-scale system should it be funded.

Statement of the Situation

The present equipment was designed and constructed as a rapid 'proof of principle' apparatus only, and was never intended to produce large quantities of treated flour. Also, as we operated it, we discovered many additional features that we needed in order to conduct proper studies.

We have not exhausted the necessary 'tweaking' studies on the treated flour. It is quite common for bakers to make small changes in their formula or process, often without actually being conscious that they are doing so, but they do not consider that they are changing their formula. To have the best chances for success, it is desirable for the 'new' chlorine-free flour to substitute directly for the cake flour they are accustomed to use. This may not be possible, but small adjustments are likely to be tolerated.

For example, there are some physical process changes that could be implemented easily in most bakeries. This includes but is not limited to changes in the mixing operation such as speed, time, and whip or beater design. Mixing 'style' also could be changed (all-in, batter, sugar-cream, etc. methods).

Most bakers would accept relatively easily some general minor formula modifications such as water amount, emulsifier quantity and type, and chemical leavening amount & type (in cakes that use it).

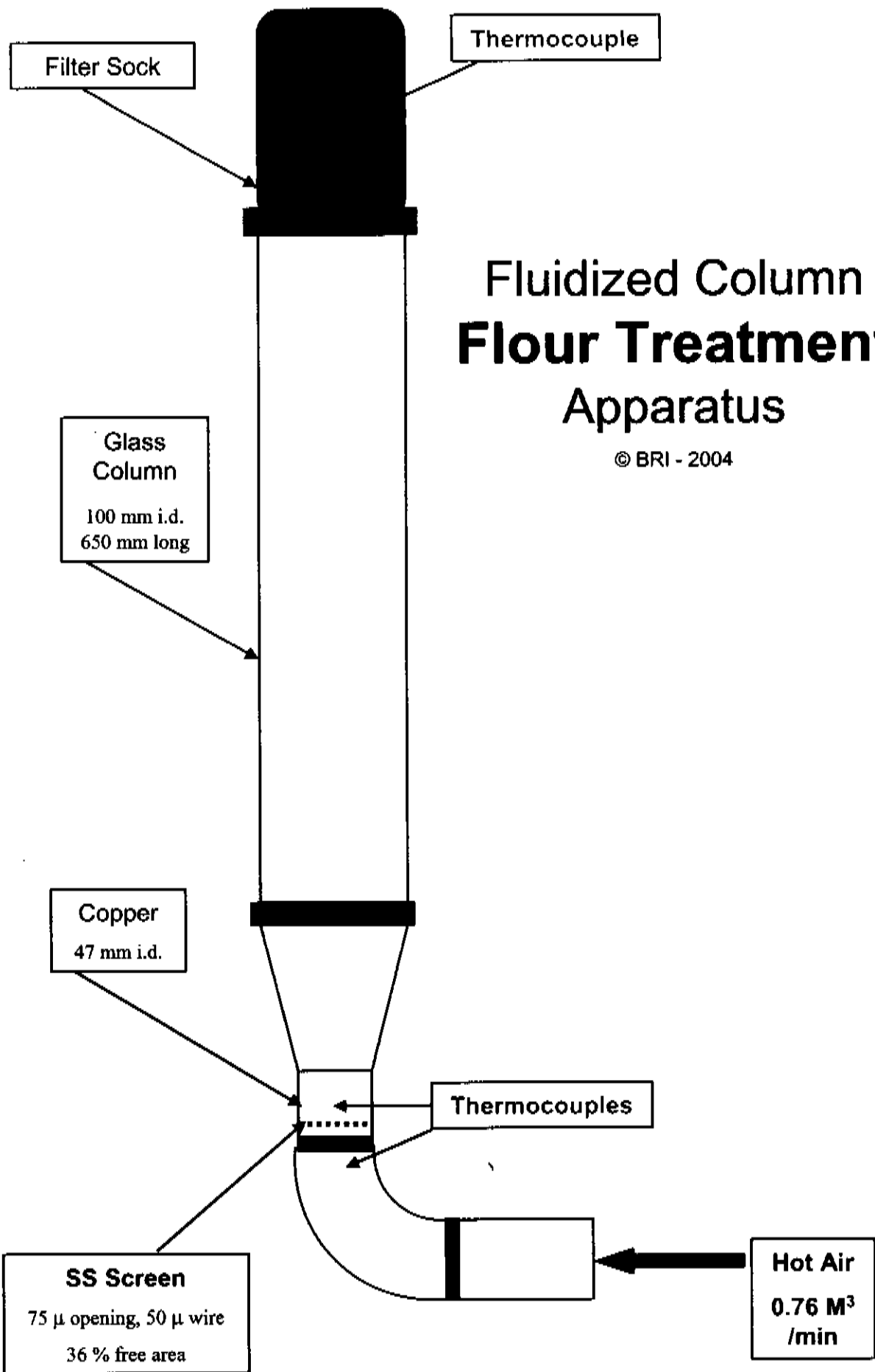
Likewise, changing in baking procedures such as time and oven temperature are known to have effects on batter density, viscosity, and bubble size, with resultant effects on final cake volume and grain and texture properties. These, along with the adjustments above, could be easily adopted by the baker provided they were given general directions for the new flour such as 'must use this new special emulsifier', 'increase water by X %', 'increase/decrease mixing action', etc.

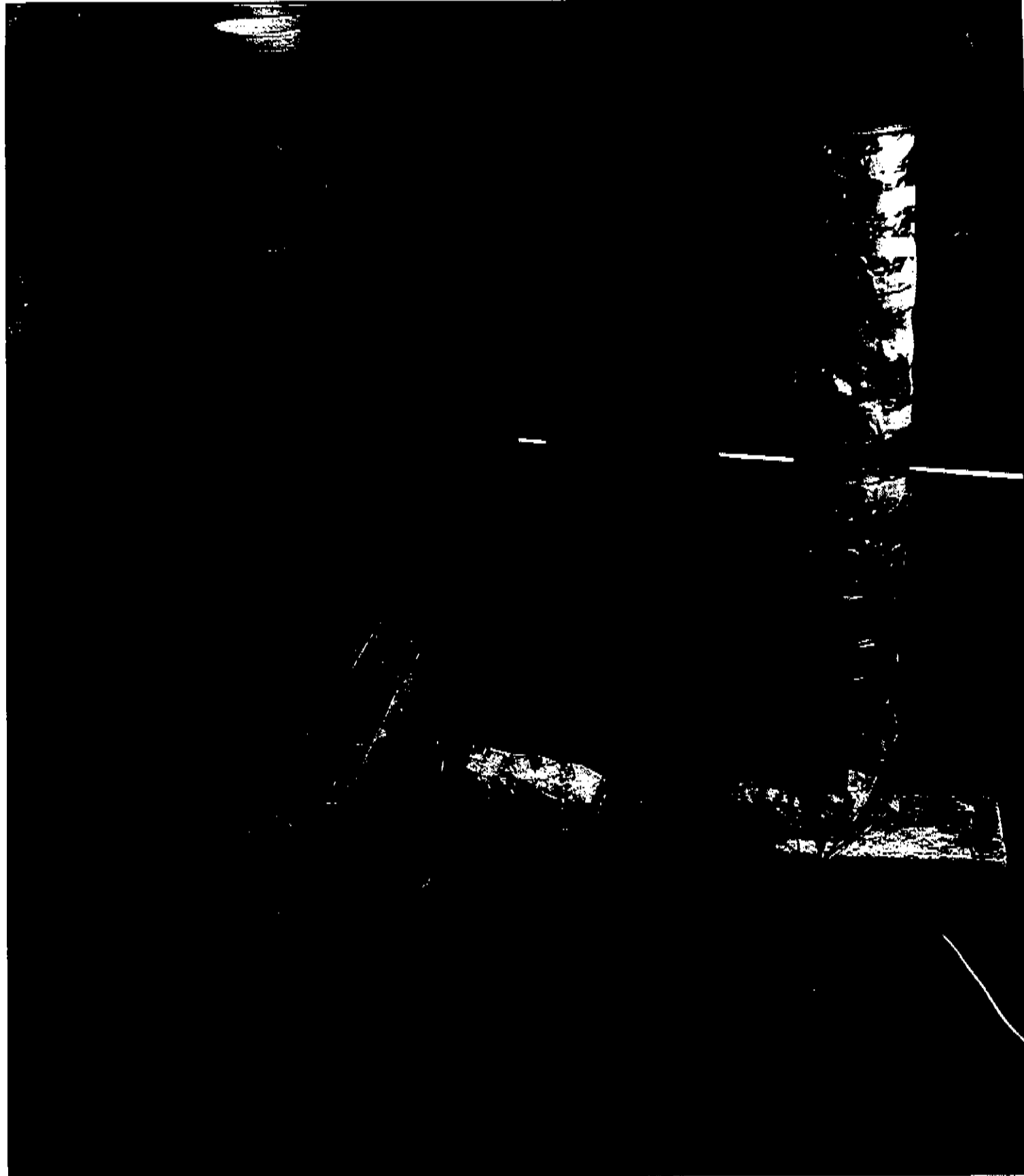
The new flour treatment must be studied over a wider range of formula types, equipment, and procedures. The 'robustness' must be determined, both for producing the flour (variety, protein, particle size, etc.) and for using it.

Future studies must be conducted with sufficient rigor and replication that they could be published in a refereed journal and possibly patented. Only in this manner can the process attain respectability and acceptance in the scientific & trade communities.

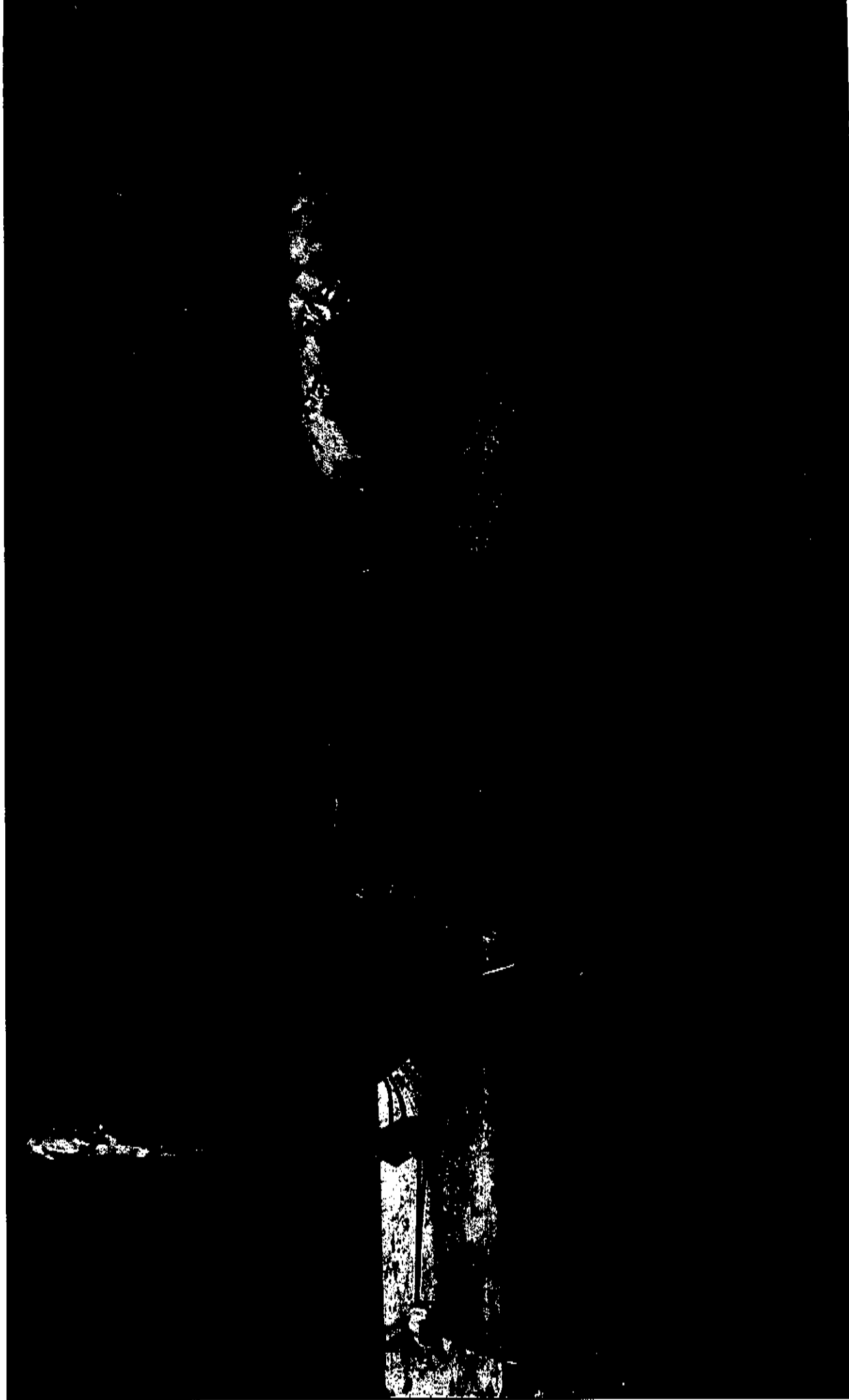
It is not possible to accurately determine the optimum conditions for production and for utilization without several large consistent flour batches. To do this, we must have a larger (small pilot scale) batch model fluidizer that is fitted with proper instrumentation. It must also be large enough to provide small quantities of flour for testing by interested millers and bakes. A batch size of about 10-Kg might be an appropriate step-up from the present 300-g capacity apparatus. Experience with that scale could then make possible the design & construction of a much larger scale, perhaps continuous, heating-fluidizer.

Hence, we recommend additional funding for this next stage.





Flour Heat Treatment Fluidizer



Connection Details - Flour Heat Treatment Fluidizer

From: "Dan Brabec" dan@gmproc.ksu.edu
To: c.walker@bri.com.au
Cc: "Floyd Dowell" fdowell@gmproc.ksu.edu

Subject: flour dust ignition temperature

Date: Wed, 18 Feb 2004 10:30:53 -0600

To: C. Walker

From: Dan Brabec, USDA-ARS Grain Marketing Res, Eng. Unit

Regarding: dust ignition

The simple answer is 440 C for wheat flour. This value was referenced from a chart produced by the U.S. Bureau of Mines prior to 1984.

This was the ignition temperature of a dust cloud (dispersed particles), of fine dust particles (passing 200 mesh sieve), and of low moisture content. It was probably one of the most flammable conditions. The ignition temperature does vary with the parameters cited above.

A layer of wheat flour would have a higher ignition temperature since it is not dispersed particles.

Corn flour was cited as having a 400 C dust cloud ignition temperature.

Lesikar (1991) cited wheat dust (not processed flour) as having a minimum ignition temperature of 645 C.

This was probably because wheat dust contains larger fractions of inert materials.

And Schoeff demonstrates the flammability of a small amount of idle cornstarch in the "Deadly Dust" videos.

A small amount of starch is placed in a bowl and in one side of a double chamber. The powder is blown out of the bowl with a blast of air and towards a glowing red electrical wire where the dust cloud ignites, changing the powder into a plume of hot gas and flames which then disperses and ignites idle dust in the secondary chamber and vents out the top of the second chamber.

Other information was found on the internet using the search terms "dust ignition temperature".

Sincerely

Dan Brabec

John,

Explosion characteristics of Grain Dust:

- Ignition temperature of dust clouds (Å°C) = 430
- Min. spark energy required for ignition of dust cloud (millijoules) = 30
- Min. explosive concentration (oz per 1,000 cu ft) = 55
- Rate of pressure rise (psi per sec) = Avg: 1,000 Max: 2,750

Hope this helps

Pierre

Pierre G. Frenette, ROHT, OHST
Health & Safety Officer (Occupational Hygiene)
WHSCC - CSSIAT
1300 St. Peter Avenue, Suite 220
Bathurst, N.B.
E2A 3A6

Tel: (506) 547-7391
Fax: (506) 547-7311
Email: frenettp@whscc.nb.ca

-----Original Message-----

From: John Orser [<mailto:jorser@orserenvironmental.com>]
Sent: January 15, 2002 9:16 AM
To: HS-Canada@list.ccohs.ca
Subject: HSC: Grain Dust

Can anyone tell me the in-air concentration of grain dust that would =
cause an explosion? I have looked and I can't find it. Units of mg/m3 =
would be appreciated.

Regards,
J. Orser

John R. Orser, OHST, ROHT, Environmental Technologist
Orser Environmental & Safety Inc.
195 King Street, Suite 204
St. Catharines, Ontario, Canada L2R 3J6
Voice 905-688-0500 Fax 905-688-4746
jorser@orserenvironmental.com
<http://www.orserenvironmental.com>

Fluidization & De-entrainment

When designing fluidization equipment, as in the heat treatment apparatus described, it is necessary to make estimates of the minimum air velocity required to fluidize the particles and the maximum velocity (terminal velocity) in the de-entrainment section. Traditionally, entrainment occurs in a zone with a smaller cross-sectional area and de-entrainment in a much larger area so the air velocity drops below the terminal velocity for the particles. In both cases, the velocities of interest are a function of both the particle diameter and the differences in densities of the particles and the entraining fluid.

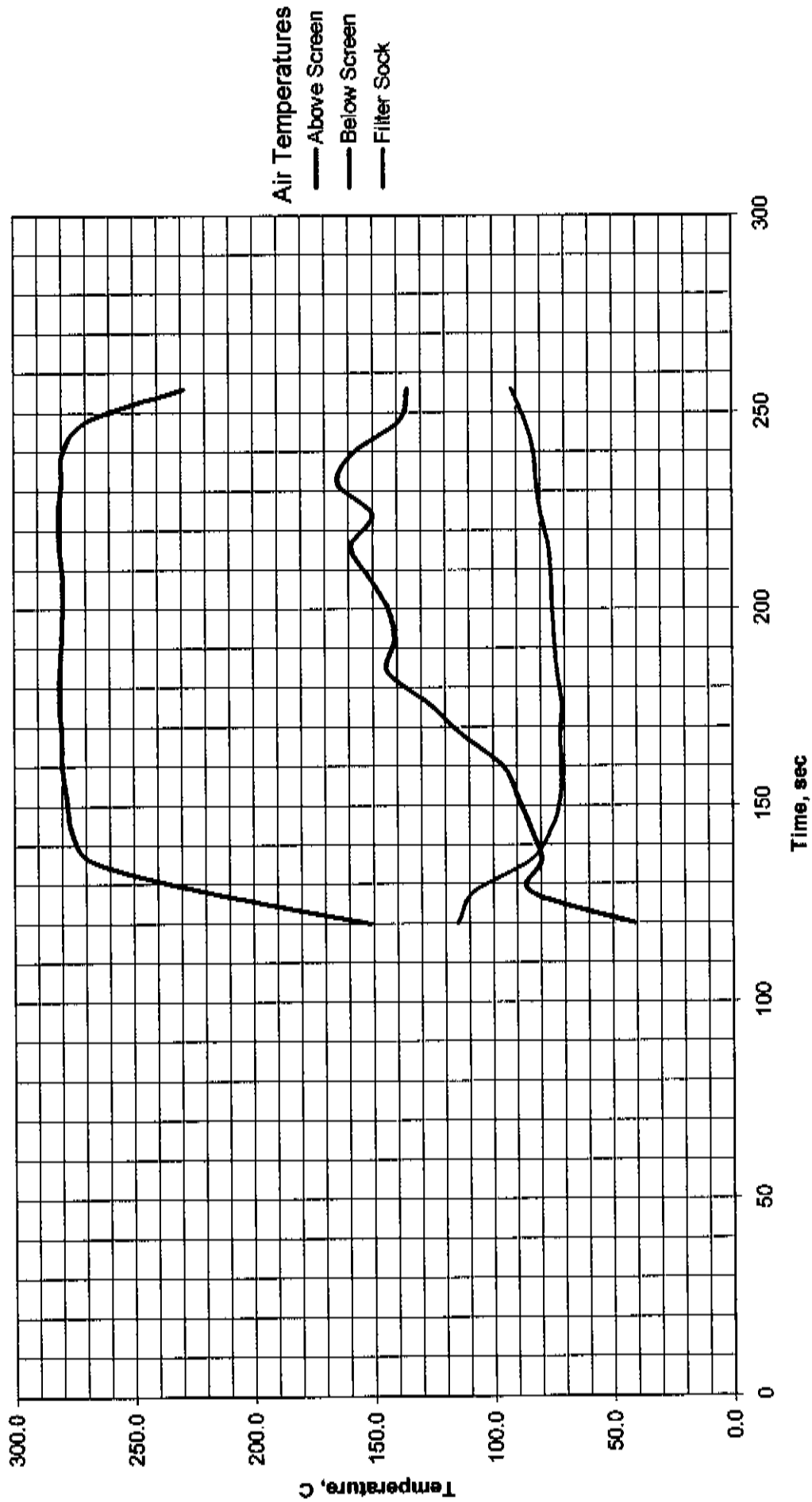
Mr. John Kalitsis designed the relative diameters for the two sections in the apparatus, based upon theoretical considerations and an average flour particle diameter. Using that original work as a basis, we calculated the terminal and fluidization velocities for flour at 20 μm and at 149 μm , representing the major range normally encountered in wheat flour. The actual velocity was then measured with a fan-type velometer at room temperature and adjusted for the change in temperature actually in use.

	<u>Velocity: (M/sec)</u>		
	<u>Calculated Values</u>		<u>Section Measured</u>
	<u>20 μm</u>	<u>149 μm</u>	
Fluidization	0.23	8.63	3.6
Terminal	0.95	2.59	0.9

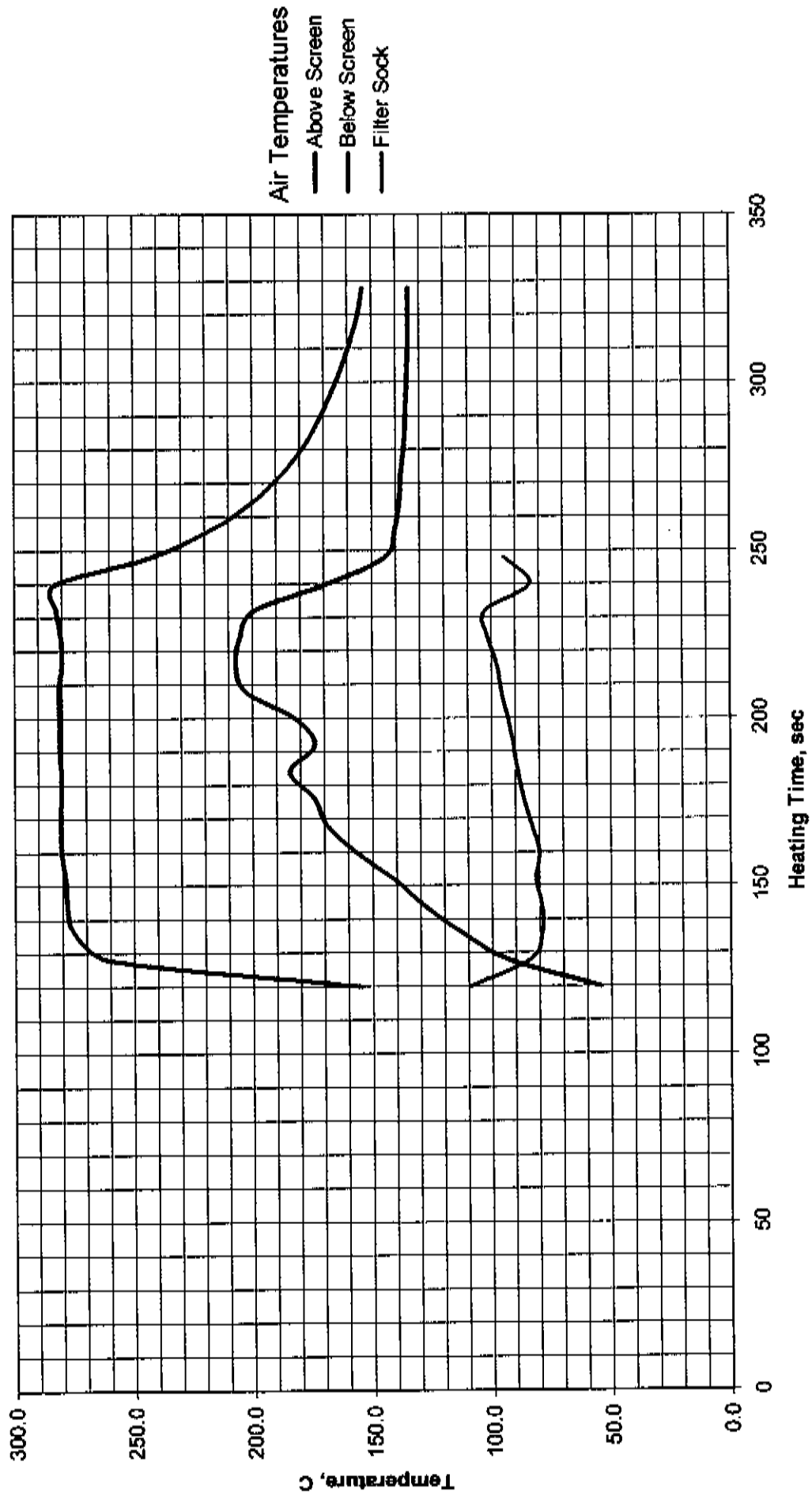
Based upon the above calculations and actual observation, there needs to be greater than the present 4:1 difference in areas for the two sections, because of the wide range of flour particles normally encountered, especially in finely-milled soft wheat cake flours. There was still a substantial amount of flour reaching the filter sock at the top of the column, causing an uncertainty in the exact amount of time and temperature part of the flour had been exposed to. Since fluid velocity varies across the cross-section of a tube in approximately a parabolic profile, it will always be higher in the center and lower near the walls. As a result, cross-section areas and airflow rates need to be carefully considered in light of the particle diameters encountered.

TABLE-XXX								
Pin-Milled Flour Heat Treated on 29 March 04 (Nominally treated 2 minutes with 310 C air) (Not pre-dried flour)								
Allied Internal Control Cake Flour								
BRI # L0328								
Temperatures								
Description	Avg. Air Temp. Below Screen	Max Air/Flour In Fluidizer	Flour Final When Air Off	Flour Temp When Dumped	Final Air in Filter Sock	Energy in, Deg-Min	Cake Vol. cc	Cake Score
Chlorinated L0327						N/A	1514	83
Non-Chlorinated L0328-Not Heated						N/A	1342	54
Heat Treatments, first of duplicated series.								
Heat Treatments for 2 min @ 310 C setpoint								
Not Pin Milled			142				1410	64
Pin Milled One Pass			154				1438	72
Pin Milled two passes			145				1410	69
Duplicated Heat Treatments with Data Logger in place								
Not Pin-Milled	267	165	139	132	89	257	1364	60
Pin Milled 1 Pass	271	207	141	135	103	341	1419	68
Pin Milled 2 Passes	269	188	143	136	110	323	1364	60
Trial with holding after heat treatment								
Not Milled, 13 min tot.								
Treatment-2	269	142	131	---	115	236		
Hold-11	---	---	---	115	---	1362		
Total-13	---	---	---	---	---	1618	1375	66

0-Passes Through Pin Mill

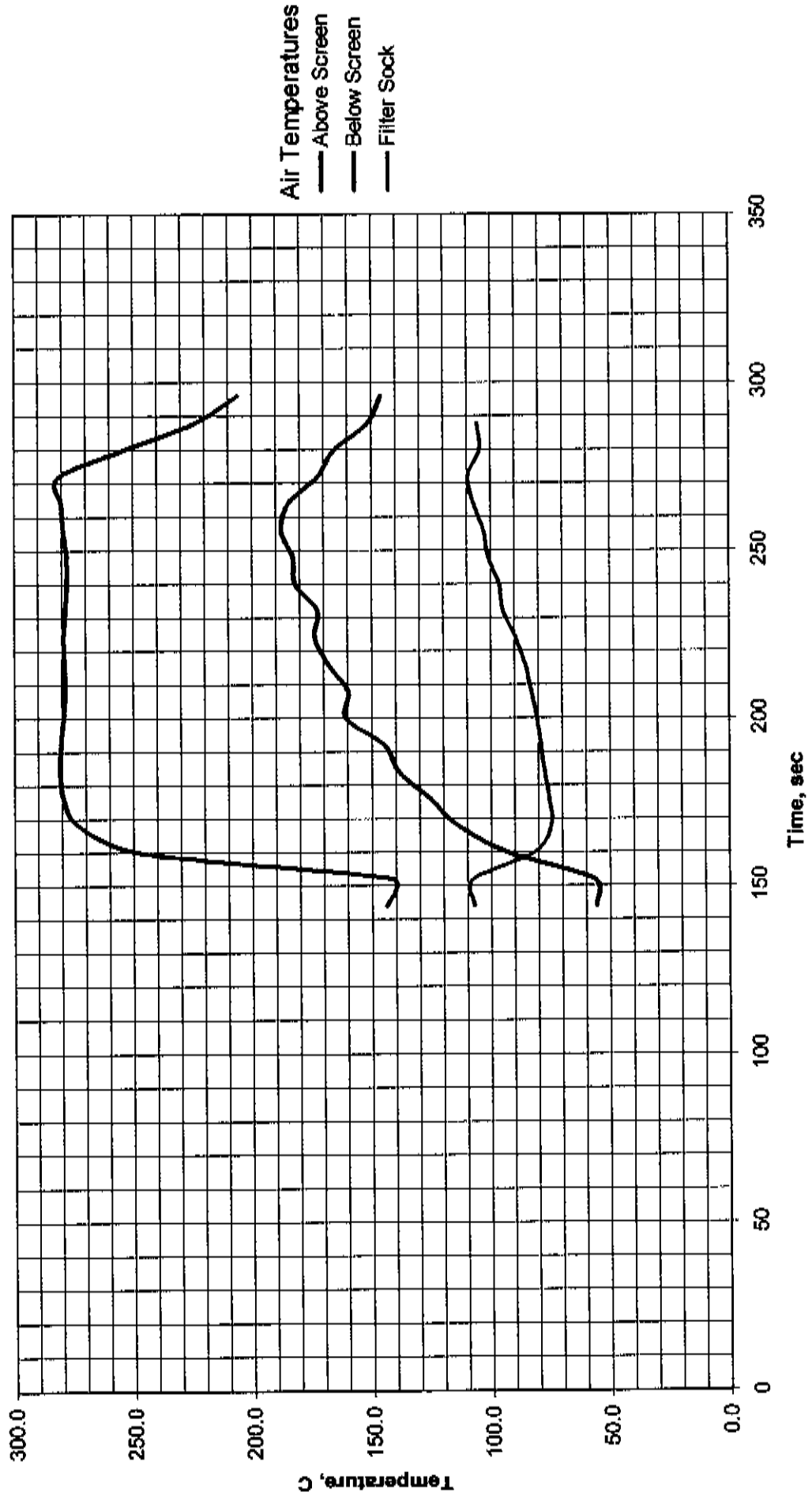


1 PassThrough Pin Mill



Air Temperatures
— Above Screen
— Below Screen
— Filter Sock

2-Passes Through Pin Mill



0-Passes, Long Hold Time

