

A METHOD TO MEASURE CARBON DIOXIDE RELEASED
FROM AND CONTAINED IN YEASTED DOUGHS

by

ARTHUR RAY THACKERY

B.A., Wichita State University, 1971

A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

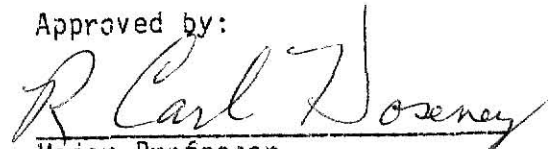
Department of Grain Science and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1982

Approved by:


Major Professor

SPEC
COLL
LD
2668
T4
1982
T54
C.2

A11200 095690

i

TABLE OF CONTENTS

	Page
INTRODUCTION.	1
LITERATURE REVIEW	2
Origin of Gas Cells in Bread Doughs	2
Measurement of Carbon Dioxide in Bread Doughs	2
Carbon Dioxide Loss During Proofing and Baking.	3
Defatted Flour Loaves	4
MATERIALS AND METHODS	5
Flour	5
Flour Defatting	5
Shortening.	5
Sodium Stearoyl-2-Lactylate (SSL)	5
Gasograph	5
Straight Dough Formula and Procedure.	6
Resistance Baking Oven.	6
Production of CO ₂ Free Water.	10
Carbon Dioxide Collection During Proofing and Baking.	10
Carbon Dioxide Quantification	13
Total Carbon Dioxide Present in Dough at the End of Proof	13
RESULTS AND DISCUSSION.	15
Gasograph: CO ₂ Produced and Released	15
Use of the Carbon Dioxide Electrode to Measure CO ₂ Released During Proofing and Baking	15
Sources of CO ₂ Contamination in the System	15
Generation of the Standard Curve for CO ₂ Concentration	17
Recovery of a Known Quantity of Carbon Dioxide	18

Total Carbon Dioxide Present at the End of Proof.	19
Carbon Dioxide Released During Proof.	20
Carbon Dioxide Released During Resistance Baking.	20
LITERATURE CITED.	44
ACKNOWLEDGEMENTS.	46

INTRODUCTION

Carbon dioxide is one of the major leavening gases in yeast raised bread. Part of the carbon dioxide produced by yeast metabolism escapes or is released from doughs during fermentation, proofing, and baking. One of the major effects of shortening in bread is to increase the volume. Daniels and Fisher, (1976) have explained the larger volume as a delay in the release of carbon dioxide during baking. Work by Junge (1980), using a resistance oven and a titration procedure to determine carbon dioxide, attributed the larger volumes for loaves with shortening to delayed loaf setting. In recent years, a device for measuring carbon dioxide concentrations of aqueous solutions directly has been made available commercially: a carbon dioxide electrode.

Our goals were to determine the usefulness of the carbon dioxide electrode to measure carbon dioxide released from loaves during the proofing and baking; to determine if shortening delayed carbon dioxide loss; to determine if sodium stearoyl-2-lactylate (SSL) had the same effect as shortening on carbon dioxide release; to determine if carbon dioxide release was a factor in the volume difference observed in doughs made with defatted flours; and to determine the relationship between total carbon dioxide present in the dough at the end of proof and the amount of carbon dioxide lost in baking.

LITERATURE REVIEW

Origin of Gas Cells in Bread Dough

Yeast produces carbon dioxide as a product of fermentation. The carbon dioxide produced is dissolved in the aqueous phase of dough until it saturates that phase and diffuses into existing gas cells, causing them to expand. The necessity of incorporating air cells into the dough during mixing has been shown by several workers (Hlynka, 1972; Baker and Mize, 1941). The extremely high pressure required to create any new bubbles is because of the inverse relationship between the internal pressure in the bubble and the radius of the bubble ($p = \frac{2\gamma}{r}$, where p = internal pressure, γ = interfacial tension, and r = radius of the bubble). Baker and Mize (1941) stated that the air contained in flour is not sufficient to leaven dough, nor does it provide a sufficient number of gas cells to accept the carbon dioxide that is produced during fermentation and give rise to the fine texture in bread. They showed that the gas required to produce the cells in bread is incorporated in the latter portion of mixing. In a later work (1946), they attributed the fine cell structure of bread to gas cell subdivision, which results from those processes which impart work to the dough.

Measurement of Carbon Dioxide in Bread Doughs

Gas production and retention are regarded as two of the most important factors in determining flour quality. Several methods have been used to measure those parameters. The techniques are generally divided into three categories: those that measure volume at constant pressure (Bailey, 1939; AACC approved methods 22-14; Elion, 1933; and Rubenthaler, et al, 1980); those that measure pressure at constant volume (AACC approved methods, 22-11; Mita, et al 1977 and 1978), and the Brabender Oven Rise Recorder—a method which measures the change in buoyancy of a dough piece as volume

increases when the dough is heated in an oil bath (Marek and Bushuk, 1967). Additionally, Bloksma (1978) noted that, "...most methods for determining total gas production can be modified to measure only the gas retained in the dough by absorbing released carbon dioxide in a solution of alkali."

Reed and Peppler (1973) estimated that 55 mg. of carbon dioxide could be dissolved in the aqueous phase of 100 g of dough. Hibberd and Parker (1976) reported a solubility constant for carbon dioxide in dough of 1.44 mg/g at 27°C and 1 atm.

Carbon Dioxide Loss During Proofing and Baking

Junge (1980) reported that the amount of carbon dioxide lost (released) during proofing of doughs was essentially the same for loaves made with or without shortening. Daniels and Fisher (1976) showed an induction period for carbon dioxide loss (release) for doughs baked in a closed container in a conventional oven. Their results also showed that loaves containing fat (shortening) had a delayed release of carbon dioxide compared to loaves made without fat. Baker and Mize (1939) and Daniels and Fisher (1976), both postulated that carbon dioxide was released during baking by a heat trigger or "transition temperature".

A method for baking crustless bread was described by Baker and Mize (1939). In this method, dough is heated by passing an electrical current through it; the resistance of the dough to the passage of the current causes the temperature to increase, baking the loaf. This method causes the dough temperature to increase uniformly, without the establishment of a temperature gradient which occurs when an external heat source is used to bake bread. Junge (1980) used a modification of this system. He reported only small amounts of carbon dioxide released from loaves when baked in this manner. Additionally, he found no difference in the time of car-

bon dioxide release nor in the amount of carbon dioxide released for loaves made with or without shortening. When using an external heat source (oven) for baking, his results were comparable to those of Daniels and Fisher (1976).

Defatted Flour Loaves

Pomeranz, et al, (1968) reported that shortening improved loaf volume and grain, while loaves made from flour that had been extracted with petroleum ether showed a mixed shortening effect: defatted strong flours had reduced loaf volume with shortening and defatted weak flours had increased loaf volume with shortening. In another report, Daftary (1968), the deleterious effects (on loaf volume) were negated by the addition of polar lipids that had been previously extracted from flour.

In Junge's work (1980), he noted that defatted flour loaves had greater heights than regular flour loaves and they achieved those heights at a faster rate than did the regular flour loaves.

MATERIALS AND METHODS

Flour

A hard winter wheat flour (BCS-78) experimentally milled from a composite of many wheats harvested throughout the Great Plains was used in all experiments. It contained 12.2% protein (N X 5.7) and 0.45% ash (14% moisture basis).

Flour Defatting

This same flour (BCS-78) was extracted in a large Soxhlet apparatus with petroleum ether (boiling range 35⁰-60⁰C) to remove free lipids. The extraction was carried out for 24 hours on a 450 gram sample. Heating was adjusted to insure a complete change of solvent twice per hour. The extracted flour was air dried at room temperature for 24 hours to remove residual solvent.

Shortening

For doughs made with shortening, Creamtex (Durkee Foods, SCM Corp., Cleveland, Ohio) was used. It is a partially hydrogenated vegetable oil derived from soybeans, palm, and cottonseeds.

Sodium Stearoyl-2-lactylate (SSL)

Sodium Stearoyl-2-lactylate, Sterolac S (ITT Panipulus, Olathe, Kansas), was used as a substitute for shortening in some of the test doughs.

Gasograph

Flours were slurried for 1.5 min in 15 ml of water containing 0.15 g NaCl, 0.60 g of sucrose, and 0.20 g of fresh baker's yeast in the procedure outlined by Rubenthaler, et al, (1980). The reaction bottles were stoppered 2 min after being placed in the water bath and the fermentation allowed to

proceed for 4 hours. The peak gasograph unit value at 4 hours was then converted to cubic centimeters by multiplying the value by 2.38 (Rubenthaler, et al, 1980).

Carbon dioxide released from a dough was measured by slurrying identical mixtures and treating one as described above. The slurry in the second reaction bottle was connected to a bottle containing 50 ml of 2 N NaOH. The NaOH bottle was then connected to the gasograph recording unit. Carbon dioxide released from the slurry was then trapped in the NaOH solution. The carbon dioxide released from the slurry was calculated by subtracting the value obtained for the slurry exposed to NaOH from the value of the normal slurry.

Straight Dough Formula and Procedure

The formula given in Table 1 was used for all experiments with doughs or bread baking. The doughs were mixed with a 100 g National pin mixer (National Mfg. Co., Lincoln, Nebraska) and handled as described by Finney and Barmore (1943). In this procedure, doughs are punched after 105 and 155 minutes and panned after 180 minutes of fermentation.

Resistance Baking Oven

Dough was proofed and baked in the resistance baking oven (Fig. 1). The baking chamber was constructed from $\frac{1}{4}$ " plexiglas. The electrical connections (A) bring current to the stainless steel electrode plates (B); the carrier gas, nitrogen, flows into the upper inlets (C) passes over the dough and out through the lower outlets (D).

The corners and gas ports of the oven were sealed with silicone rubber caulk (Dow Corning, Silicone Rubber Bathtub Caulk). A rubber gasket was applied to the top of the oven and vacuum grease was used to insure a complete seal when the lid was bolted on.

Table 1. Formula used for Doughs and Baking.

Ingredients	% ^a
Flour	100.0
Sugar	6.0
Salt	1.5
Non-fat dry milk	4.0
Shortening (Durkee, Creamtex brand) ^b	3.0
Yeast	2.0
Potassium bromate	optimum
Water	optimum

^aIngredients, % based on flour weight

^bDoughs made with SSL (0.5%) contained no shortening

1

2

3

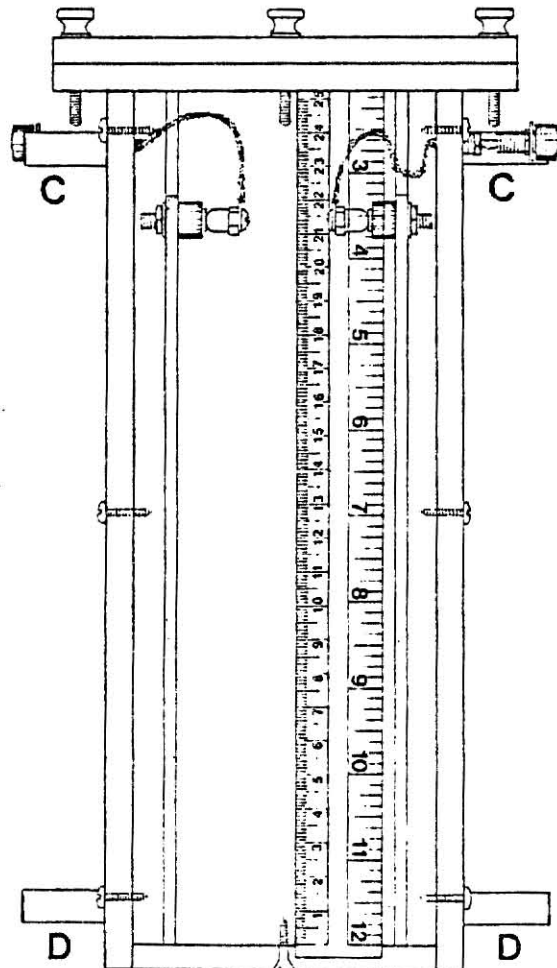
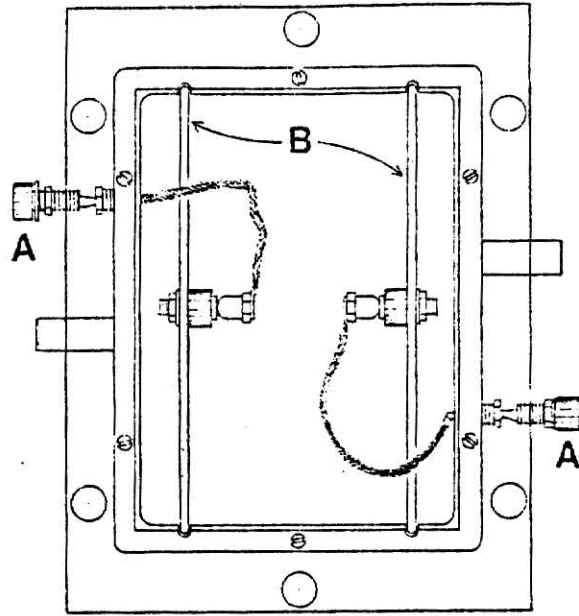
4

5

6

7

Figure 1. Resistance Baking Oven



The voltage was adjusted to the desired rate of heating (85 to 87 volts) using a variable transformer. An alcoholic solution of quinhydrone (Vogel, 1959) was used to coat the electrode surfaces. The quinhydrone decreases surface effects between the dough and the electrode plates (Baker and Mize, 1939).

Production of CO₂ Free Water

Water, free of carbon dioxide, was produced by bubbling air through a solution (approx. 10 N) of NaOH to remove carbon dioxide. This CO₂ free air was then bubbled through a vessel containing distilled water for 16 hours to remove CO₂ from the water.

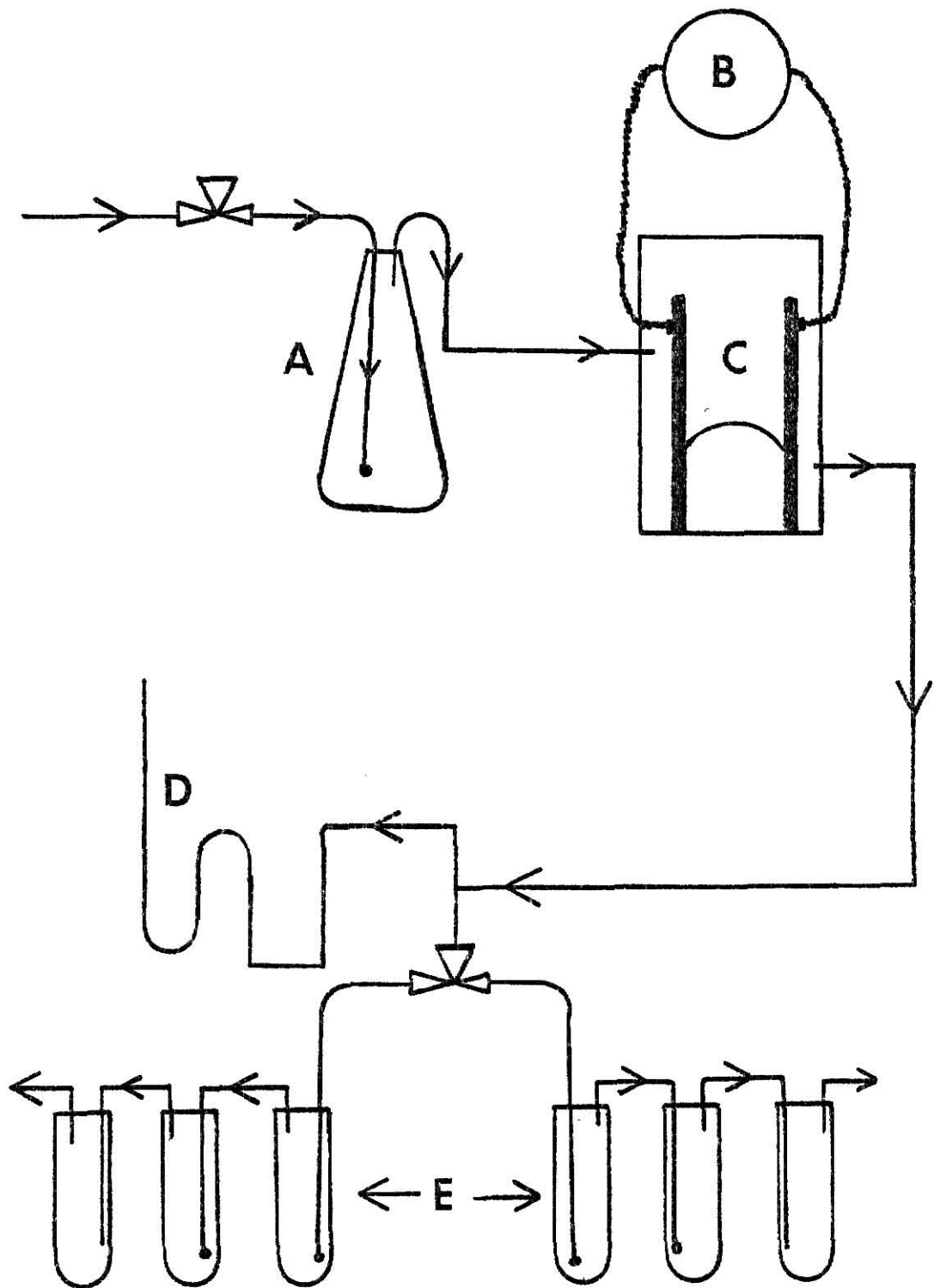
Carbon Dioxide Collection During Proofing and Baking

The schematic diagram of the apparatus used to collect carbon dioxide (CO₂) is shown in Figure 2. Arrows indicate the flow of nitrogen gas (44 ml/min). Nitrogen gas was bubbled through CO₂ free water (to prevent drying the loaf surface) and then passed through the resistance baking oven. Gaseous carbon dioxide that had been released from the dough was flushed from the resistance baking oven by the nitrogen stream and carried to the collection tubes.

The collection tubes consisted of two sets of three test tubes each. The three tubes were connected in series. The gas was introduced to the first two test tubes with gas diversion tubes and into the third test tube with a drawn capillary. Each test tube contained 25 ml of 0.2 N NaOH. Carbon dioxide was collected in the first tube of each of the two, three-tube sets. The other two tubes were used to collect any carbon dioxide not trapped in the first tube. No significant amounts of carbon dioxide were found in the overflow tubes in our experiments. After each five minute interval in the proof period and each minute interval during the baking

Figure 2. Schematic of CO₂ Collection System.

- (A) Flask containing distilled CO₂ free water
- (B) Variable Transformer, alternating current
- (C) Resistance Baking Oven
- (D) Mercury manometer
- (E) Gas dispersion tubes immersed in 0.2 N NaOH in collecting tubes



period, the gas stream was directed to the opposite set of collection tubes and the first tube removed for carbon dioxide quantification.

Carbon Dioxide Quantification

Carbon dioxide was quantified by adjusting the pH of the NaOH solution to $\text{pH } 5.0 \pm 0.2$ by adding 0.7 ml HCl and 3.0 ml of sodium citrate buffer (pH 4.5) and reading the concentration of CO_2 with a carbon dioxide electrode (model 94-02, Orion Research, Cambridge, Mass.) in combination with a pH meter (Expandomatic IV, Beckman Instruments, Inc., Fullerton, California). To determine blank values, the nitrogen gas stream was shunted around the resistance baking oven and bubbled through the collection tubes containing NaOH. Those "blanks" were subtracted from all collected CO_2 samples. After sealing the dough in the resistance oven, the gas inlet was connected to the nitrogen stream and the outflow vented to the atmosphere for 60 seconds before the outlet was connected. This flushed CO_2 from the oven.

After connecting the outlet ports, CO_2 was collected throughout the proofing cycle. After 55 minutes in the proof cabinet, the oven was removed from the proof cabinet without opening it to the atmosphere and connected to a variable alternating current transformer. Two minutes were allowed to accomplish those tasks. When the two minutes had elapsed, the gas stream was directed to fresh collection tubes, and the current turned on. The test tubes on the unused side of the system were then replaced during the first minute of baking. In this way, fresh overflow tubes were used for each cycle-proofing or baking.

Total Carbon Dioxide Present in Dough at the End of Proof

Doughs were formulated, mixed, and handled as in other experiments. After 180 min of fermentation, the doughs were moulded and panned in normal

pup loaf pans and proofed for 55 min. The dough was then removed from the pan and added to a solution (1200-1500 mls) of 0.2 N NaOH in a large stainless steel Waring Blendor Jar (model CB-4, Waring Products, Corp. New York, NY). The blendor jar had been flushed with nitrogen and held under a nitrogen blanket. The jar was capped while maintaining a positive nitrogen pressure in the jar. The contents of the jar were mixed for 15 sec at medium speed to disaggregate the dough and release trapped and solvated CO_2 into the NaOH solution. At the end of the disaggregation mix, an approximate 10 g aliquot of the slurry was removed and added to a 25 ml (approx. 25 g) aliquot of the original NaOH solution. An aliquot of this resulting solution was diluted with the original NaOH solution (total 25 ml) until a carbon dioxide concentration in the useful range of the electrode was obtained. This solution was adjusted to $\text{pH } 5 \pm 0.2$ with 6 N HCl and sodium citrate buffer (pH 4.5), before reading with the electrode and pH meter. This reading was then used to calculate the total CO_2 in the loaf as follows:

$$\text{Total CO}_2/\text{dough} = \frac{\text{grams CO}_2 \text{ in test tube}}{\text{wt. of dough in test tube}} \times \text{total wt. of dough.}$$

RESULTS AND DISCUSSION

Gasograph: CO₂ Produced and Released

Gasograph data, Table 2, showed that doughs made from regular and defatted flours, that did not contain shortening, produced approximately the same amount of gas during the 4 hour fermentation period. The defatted flour doughs released less carbon dioxide than did the regular flour doughs. Thus, it appears that a part of the increased loaf volume for defatted flour doughs is the result of the defatted dough's retaining more carbon dioxide.

There was little difference in the amount of gas produced between the regular flour doughs and the defatted flour doughs at the same temperature. More gas was produced in both loaves at the higher temperature (50°C) than at the lower temperature (30°C). Considerably less carbon dioxide was released from the defatted flour doughs at the higher temperature (50°C).

Use of Carbon Dioxide Electrode to Measure CO₂ Released During Proofing and Baking

Sources of CO₂ Contamination in the System. The carbon dioxide electrode proved to be a sensitive tool which gave reproducible measurements of the carbon dioxide concentration in our collection solutions. One must, however, guard against several sources of error when using the electrode to measure carbon dioxide.

Freshly distilled water is carbon dioxide free; however as it is exposed to air, carbon dioxide dissolves in the water. Depending upon the length of time the water has been exposed to the atmosphere, a variation in CO₂ concentration was observed in standard solutions. Use of a soda lime trap on stored quantities of CO₂ free water eliminated this source of error.

Table 2. Gasograph Data for Gas Produced and Gas Released During
a 4 Hour Fermentation.

Temperature °C	Regular Flour	Defatted Flour
	<u>Gas Produced, cc</u>	
30	47.2	48.1
50	66.0	66.9
	<u>Gas Released, cc</u>	
30	3.33	2.14
50	4.28	2.38

Reagent grade sodium hydroxide contains sodium carbonate as a contaminant to a stated maximum level of 1%. In our work, this contamination resulted in a reading of approximately 10^{-4} moles/liter of carbon dioxide for the 0.2 N NaOH solutions. This contamination was accounted for in our blank readings.

In changing the collection tubes, exposure of the collecting solution to the atmosphere was unavoidable. Although the collection tubes were flushed with nitrogen prior to filling with sodium hydroxide solution, having exposed them to the air resulted in significant readings for a "CO₂ free solution." Again, this source of error was in our blank readings.

We observed that readings taken with the CO₂ electrode were affected by previous readings. The CO₂ electrode is a standard glass pH electrode immersed (surrounded) in a solution of NaHCO₃ (electrode filler solution). This bicarbonate solution is exposed to the test solution by a membrane that is permeable to CO₂. As CO₂ from the test solution crosses the membrane to the bicarbonate solution, it changes the hydrogen ion concentration of the bicarbonate solution which is registered on the pH meter. After reading a test solution, the bicarbonate solution is "loaded" with CO₂. When reading the next test solution, an error was introduced due to residual CO₂ in the bicarbonate solution. For this reason, we "washed" the electrode between determinations on collected CO₂ samples. Our "washing" procedure was: immerse the electrode tip in a CO₂ free solution of 0.1 N NaCl (NaCl is present to prevent dilution of the electrode filler solution) until a reading corresponding to a CO₂ concentration of less than 10^{-5} was achieved. At this point, we were ready to read a new test solution.

Generation of the Standard Curve for CO₂ Concentration. The standard curve for carbon dioxide concentration was generated from collection

tubes containing known concentrations of CO_2 which were put on the collection system. An empty sealed resistance oven was flushed with nitrogen, as was the rest of the collection system. The collection system was then connected to the nitrogen stream and flushed for 6 min (3 min on each side). Then 8 tubes containing 0.2 N NaOH were placed on the system and nitrogen bubbled through them (blanks). Following those 8 tubes were 8 tubes containing 25 ml 0.2 N NaOH and spiked with NaHCO_3 to give a calculated CO_2 concentration of 0.0005 moles/liter. The next 4 tubes had no added CO_2 . Next, 8 tubes spiked with a CO_2 concentration of 0.001 moles/liter followed; then 4 tubes with no added CO_2 . Finally, 12 tubes with CO_2 concentration of 0.005 moles/liter were run.

These CO_2 samples were then read with the CO_2 electrode after adjusting the pH to 5 ± 0.2 with HCl and adding an appropriate amount of citrate buffer. Readings were taken with the pH meter set to read absolute millivolts on its expanded scale.

A regression line for the 28 points was determined. The equation of the line is:

$y = -0.439 + 0.025x$ where x is the electrode reading in mv and $y = \log \text{CO}_2$. The correlation coefficient for the line is $r = 0.998$.

Recovery of a Known Quantity of Carbon Dioxide. A known quantity of NaHCO_3 was dissolved in CO_2 free water and the solution was substituted in the collection system for the resistance oven. A gas dispersion tube was added to force the nitrogen gas stream through the bicarbonate solution. Concentrated H_2SO_4 (excess) was added to the flask to liberate CO_2 . Then, CO_2 was collected in tubes of NaOH as previously described. The gas stream was allowed to pass through the bicarbonate/acid solution for 3 hours with the collection tubes changed every 15 min. Total CO_2 recovered was 94.6%

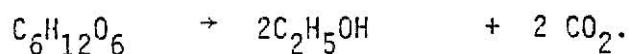
and no CO_2 was detected in the last 3 tubes (those collected past 2 hr 15 min after addition of the acid).

Total Carbon Dioxide Present at the End of Proof

Total carbon dioxide present in flour doughs averaged 18.8 millimoles for the dough with shortening and 21.0 millimoles for the no shortening dough. Ranges for replicate determinations were relatively large as evidenced by standard deviations of 4.4 millimoles and 10.8 millimoles, respectively. Values determined for doughs with shortening were: 15.4, 25.1, 16.1, and 18.5 millimoles. Doughs made without shortening gave values of: 17.7, 37.1, 15.0, and 14.4 millimoles. It was felt that the value 37.1 millimoles was not reasonable, but we could not eliminate it due to any experimental variable.

Calculations of the volumes that the CO_2 present at the end of proof would occupy are approximately 465 cc for the shortening dough and 520 cc for the dough made without shortening. These values are somewhat larger than the volumes of doughs at the end of the proof cycle, however, part of the CO_2 present is dissolved in the aqueous phase in dough. Reed (1973) estimated 55 mg. of CO_2 is contained in 100 g of dough. Our 170 g doughs would contain about 95 mg of CO_2 . That amount of CO_2 would occupy 53 cc if in the gaseous state at 30°C and 1 atm.

If one were to assume that one gram (1% of flour wt.) of the sugars present in the dough is consumed during the proof cycle according to the reaction:



One gram of sugar will produce 0.4889 grams of carbon dioxide (Quinn and Jones, 1936). At 30°C and 1 atm. pressure, the volume of CO_2 produced from 1 gram of sugar is 0.17 l (270 cc). Thus, our values (~ 500 cc) appear

reasonable and accounts for both the volume of the dough and an amount of CO_2 dissolved in the aqueous phase of the dough.

Carbon Dioxide Released During Proof

The quantity of carbon dioxide released from the various doughs is nearly the same for all doughs tested (Table 4). Graphs (Figs. 3 through 7) show that the release of carbon dioxide during proof follows the same pattern for all doughs tested. The rate of loss is very low in the early part of the proof cycle and increases gradually with time. Differences in the total quantity of CO_2 released and collected show up in the latter stages of the proof cycle. This is consistent with that reported by Junge (1980), but our total values are approximately 30% lower than those he reported. In both cases, the quantity released is very small.

Carbon Dioxide Released During Resistance Baking

Amounts of carbon dioxide released from loaves during the initial 8 min of baking were small compared to the approximate 20 mmole contained in each loaf (Table 5). The total amount of CO_2 released is also a small amount compared to the total CO_2 in the loaf. Most of the total CO_2 released is recovered in the final 12 min of baking. The total amount released from the loaf made without shortening, although still small, was nearly double the amount released from any other loaf and was approximately 3 times as much as the loaf made with regular flour and shortening.

Graphs of carbon dioxide released vs. time (Figs. 8 through 12) show that the amount of carbon dioxide released from the no shortening loaf is greater in the early stages of baking than the loaf with shortening. The graphs also show that shortening delayed the release of carbon dioxide from the loaf compared to the no shortening loaf. Again, the total CO_2 released is greater for the no shortening loaf than for the loaf with shortening.

Table 4. Total Carbon Dioxide Released During Proof

Treatment	mmoles CO ₂ Released*	Average
Regular flour, 3% shortening	0.68	0.61
	0.54	
Regular flour, no shortening	0.80	0.71
	0.62	
Regular flour, 0.5% SSL	0.71	0.76
	0.81	
Defatted flour, 3% shortening	0.80	0.73
	0.67	
Defatted flour, no shortening	0.77	0.70
	0.64	

*Values were obtained for separate, duplicate loaves.

Figure 3. Release of CO₂ During Proof vs. Time:
Regular Flour, 3% Shortening, (●) and
(★) represent different doughs.

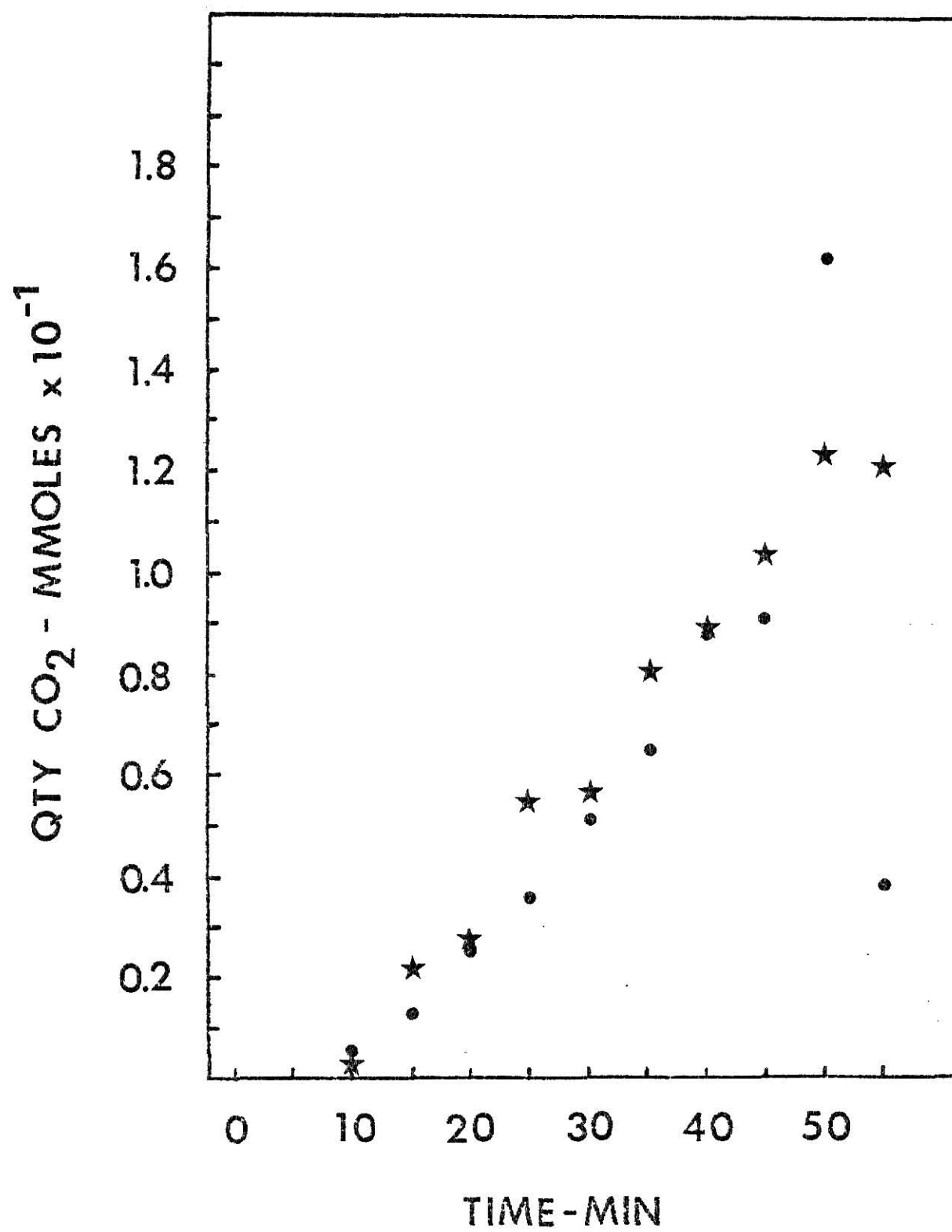


Figure 4. Release of CO₂ During Proof vs. Time:
Regular Flour, No Shortening, (●) and
(★) represent different doughs.

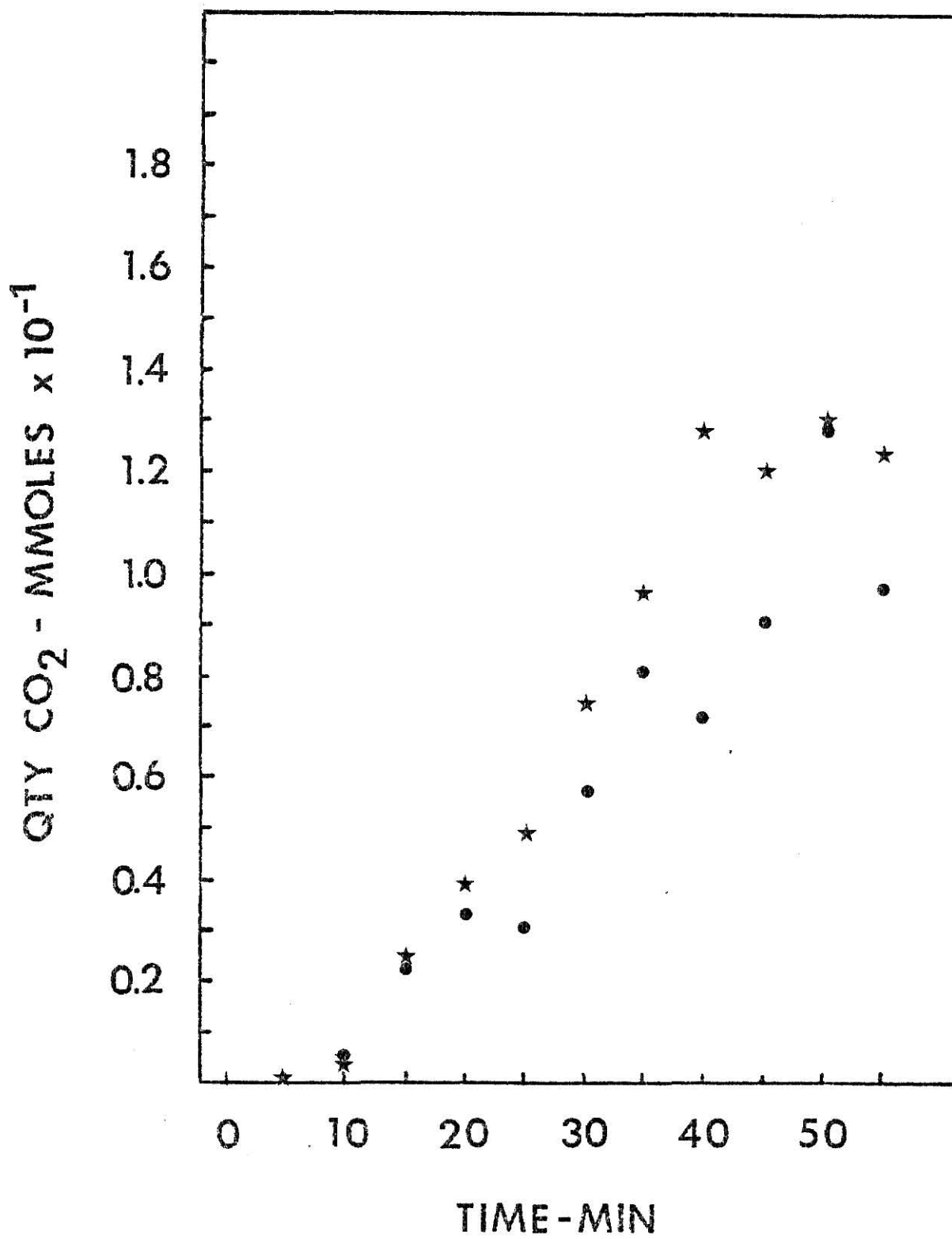


Figure 5. Release of CO₂ During Proof vs. Time:
Regular Flour, 0.5% SSL, (●) and
(★) represent different doughs.

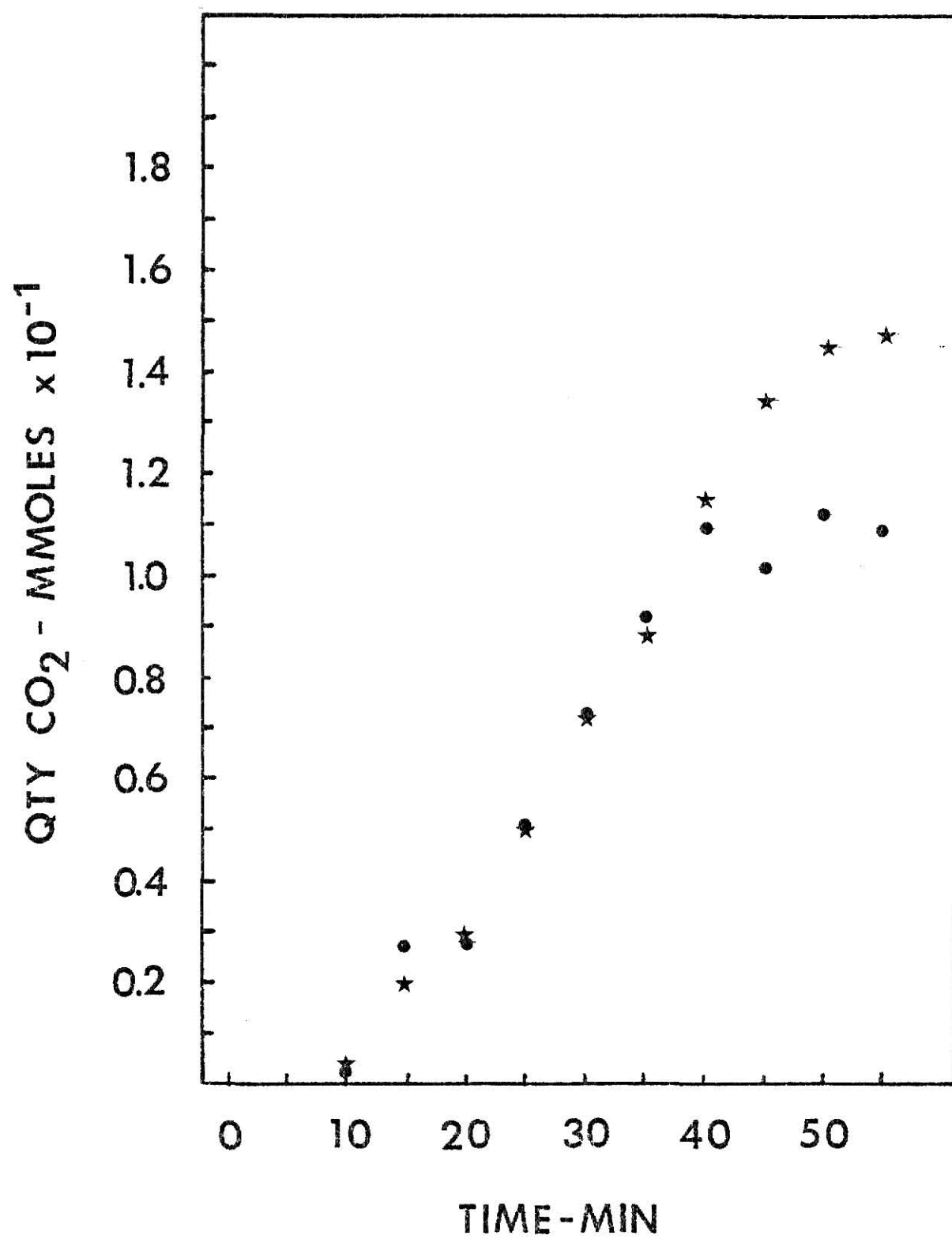


Figure 6. Release of CO₂ During Proof vs. Time:
Defatted Flour, 3% Shortening, (●) and
(★) represent different doughs.

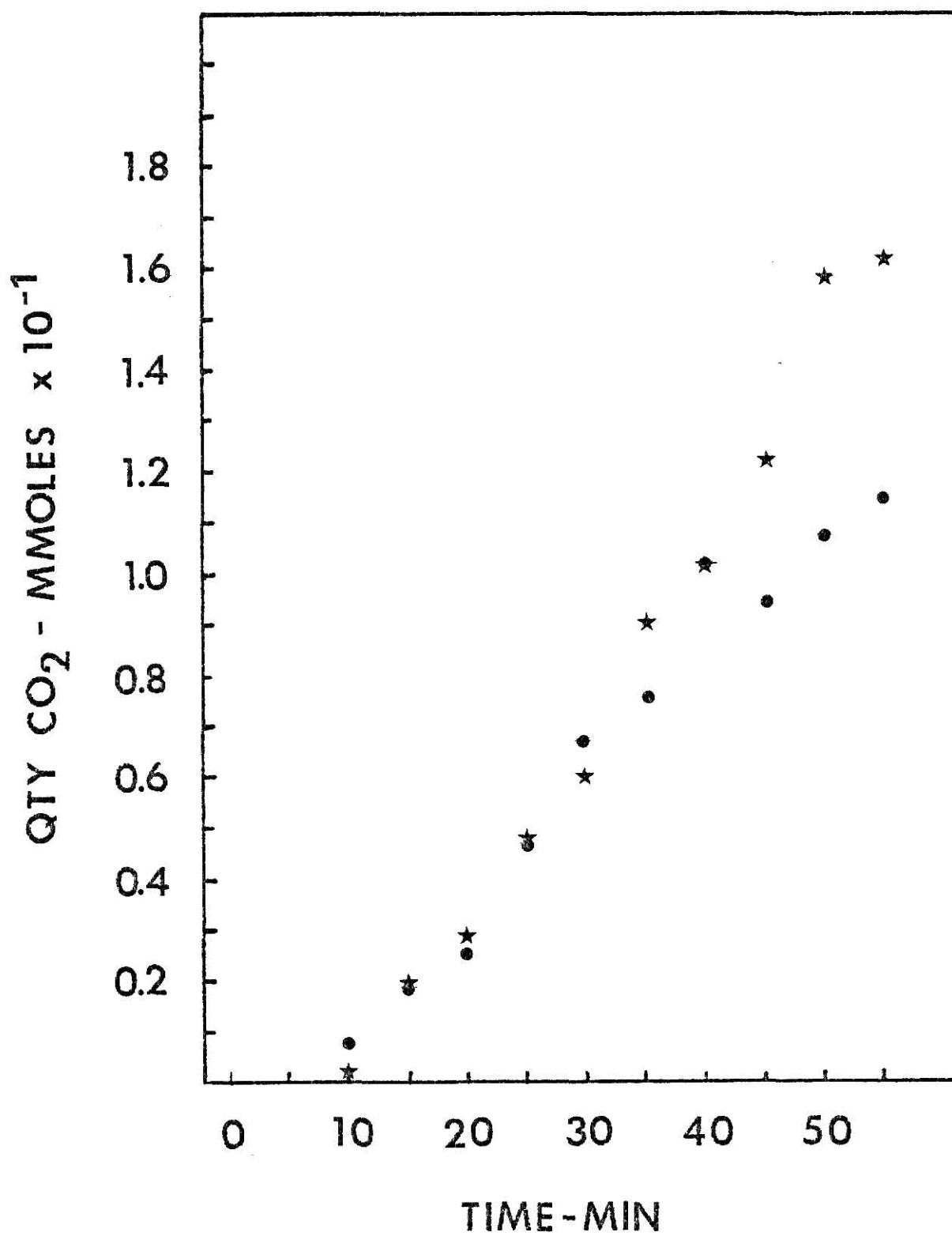


Figure 7. Release of CO₂ During Proof vs. Time:
Defatted Flour, No Shortening, (●) and
(★) represent different doughs.

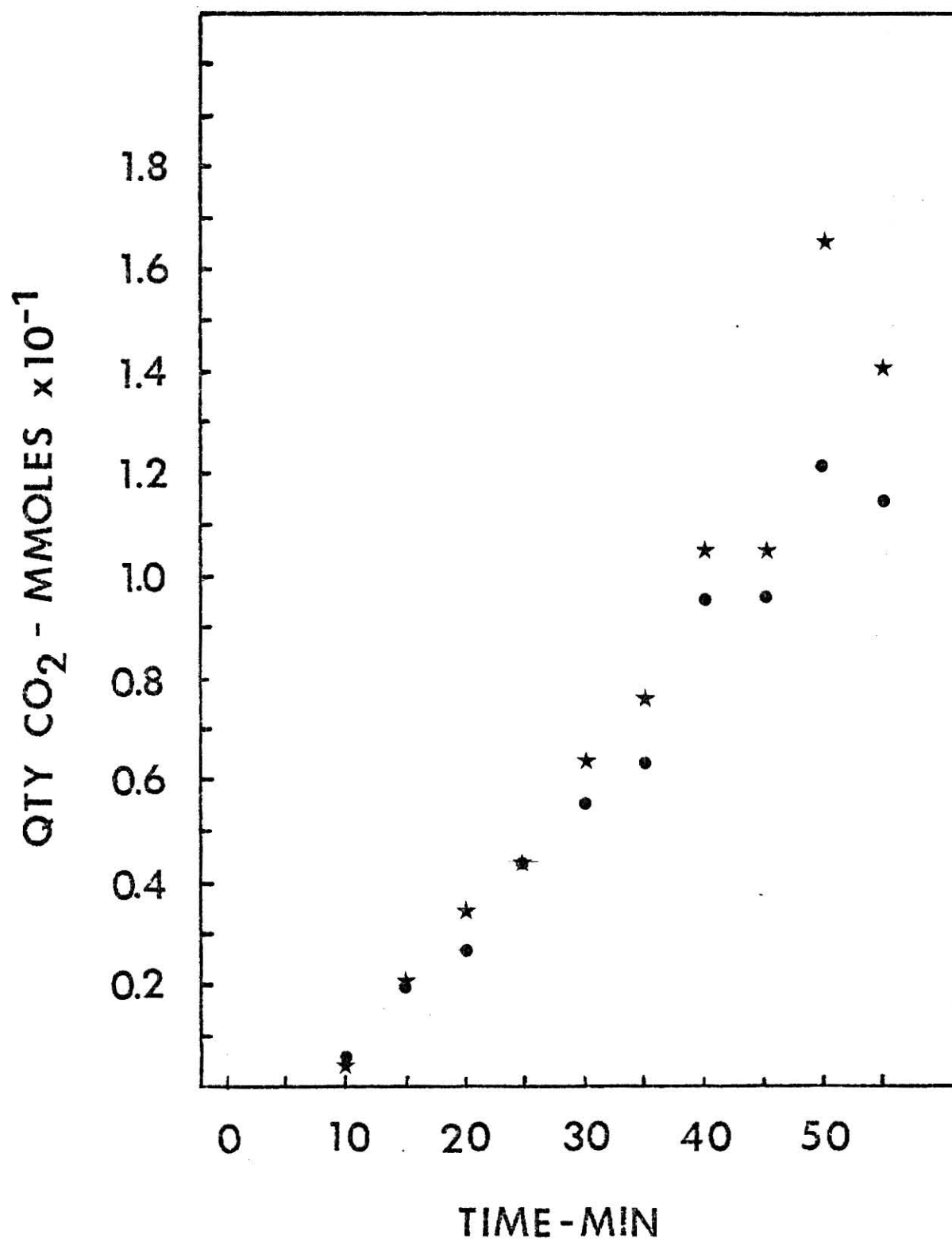


Table 5. Carbon Dioxide Released During Resistance Baking.

Formula Variable	Qty. CO ₂ Released Initial 8 min. bake time, millimoles		Qty. CO ₂ Released Final 12 min. bake time, millimoles		Total Qty. Released in Baking, millimoles	
	Average		Average		Average	
Regular flour, 3% shortening	0.29	0.28	1.72	1.25	1.99	1.52
	0.27		0.78		1.05	
Regular flour, no shortening	0.98	0.88	3.94	2.75	4.92	3.63
	0.78		1.56		2.34	
Regular flour, 0.5% SSL	0.37	0.37	1.80	1.86	2.17	2.23
	0.37		1.93		2.30	
Defatted flour, 3% shortening	0.49	0.46	3.16	2.45	3.65	2.41
	0.43		1.75		2.18	
Defatted flour, no shortening	0.29	0.42	2.33	2.51	2.62	2.93
	0.56		2.69		3.25	

Figure 8. Release of CO₂ During Resistance Baking
vs. Time: Regular Flour, 3% Shortening,
(★) and (●) represent data from different
loaves.

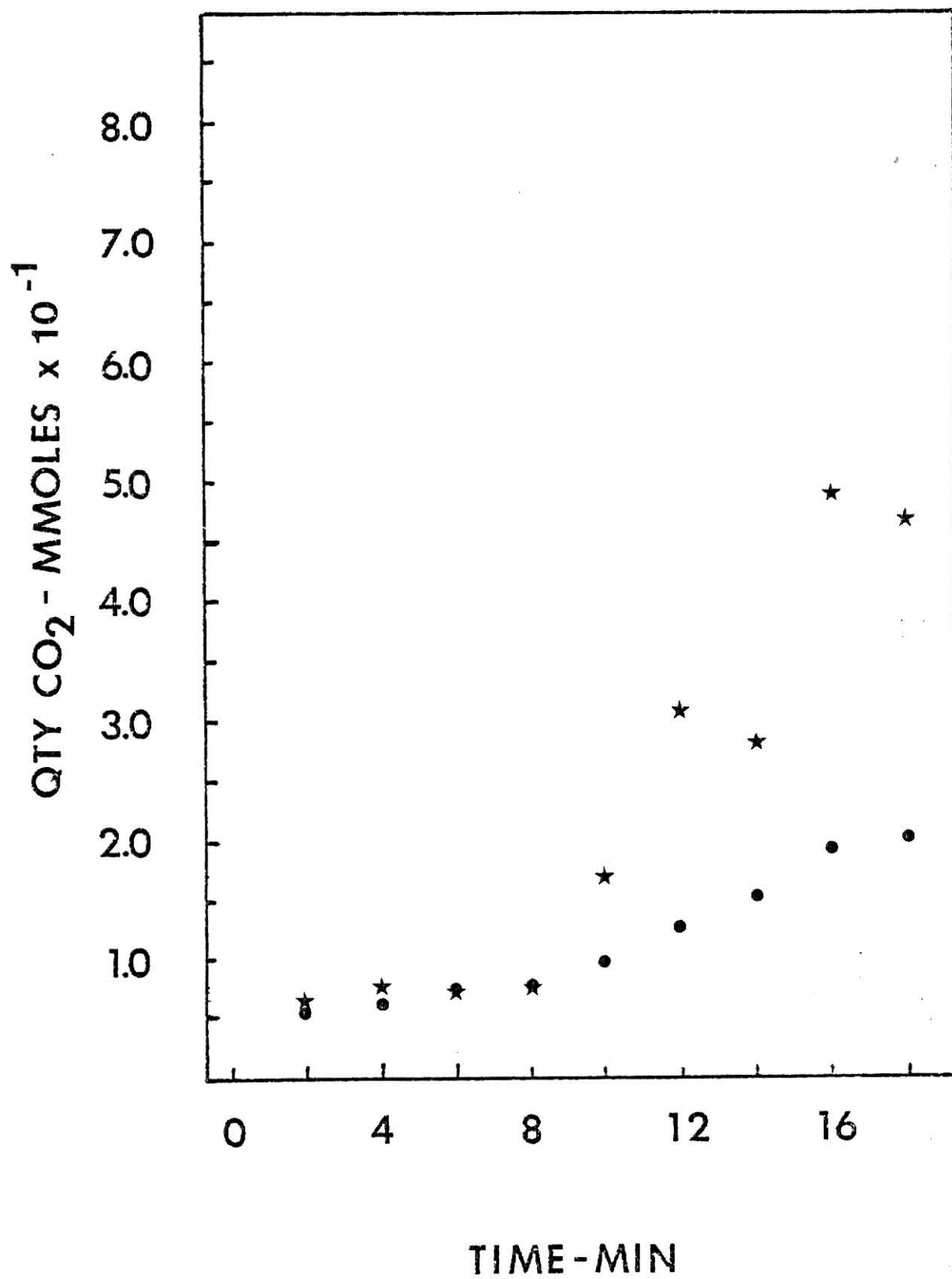


Figure 9. Release of CO₂ During Resistance Baking
vs. Time: Regular Flour, No Shortening,
(★) and (●) represent data from different
loaves.

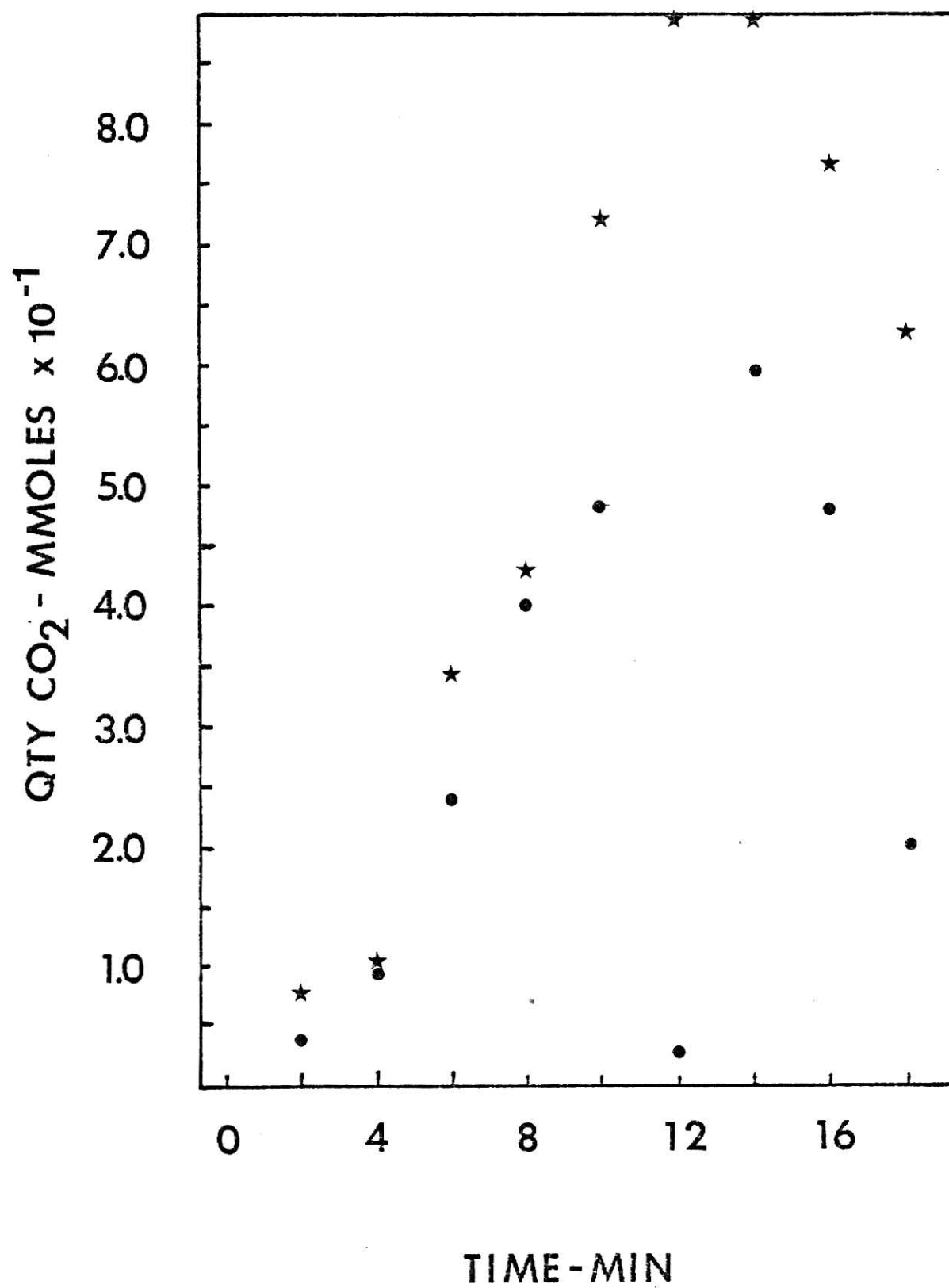


Figure 10. Release of CO₂ During Resistance Baking
vs. Time: Regular Flour, 0.5% SSL, (★)
and (●) represent data from different
loaves.

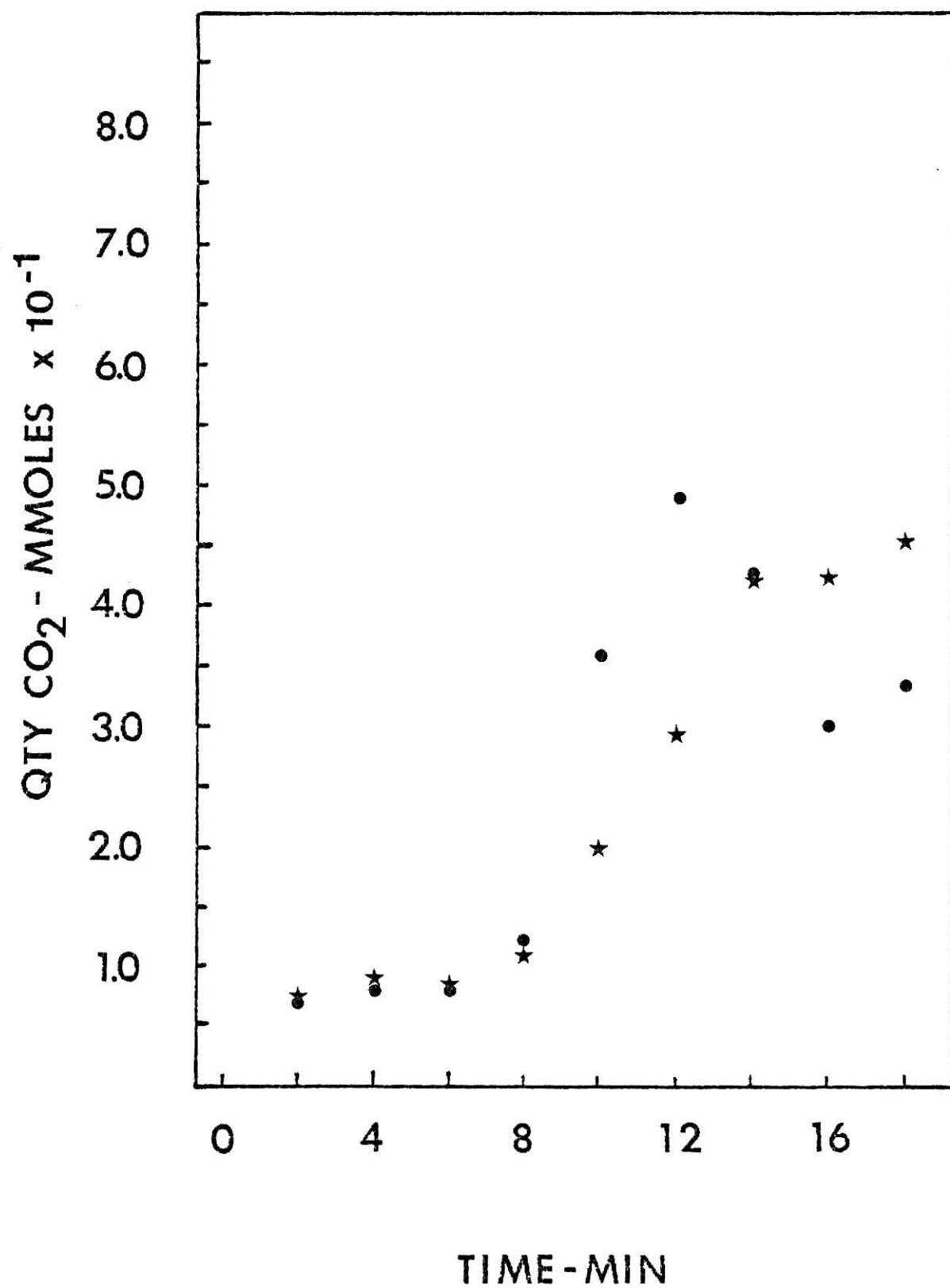


Figure 11. Release of CO₂ During Resistance Baking
vs. Time: Defatted Flour, 3% Shortening,
(★) and (●) represent data from different
loaves.

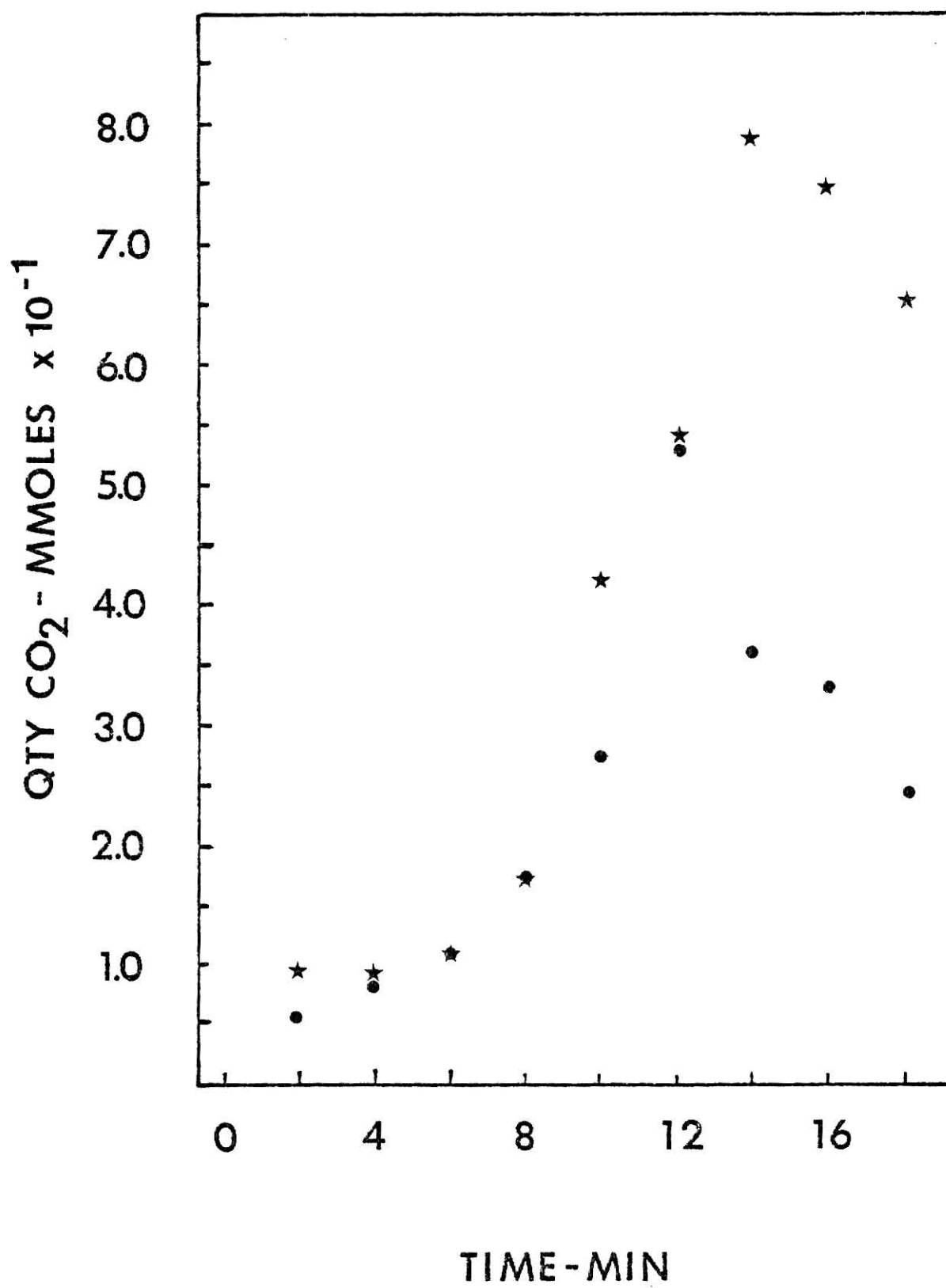
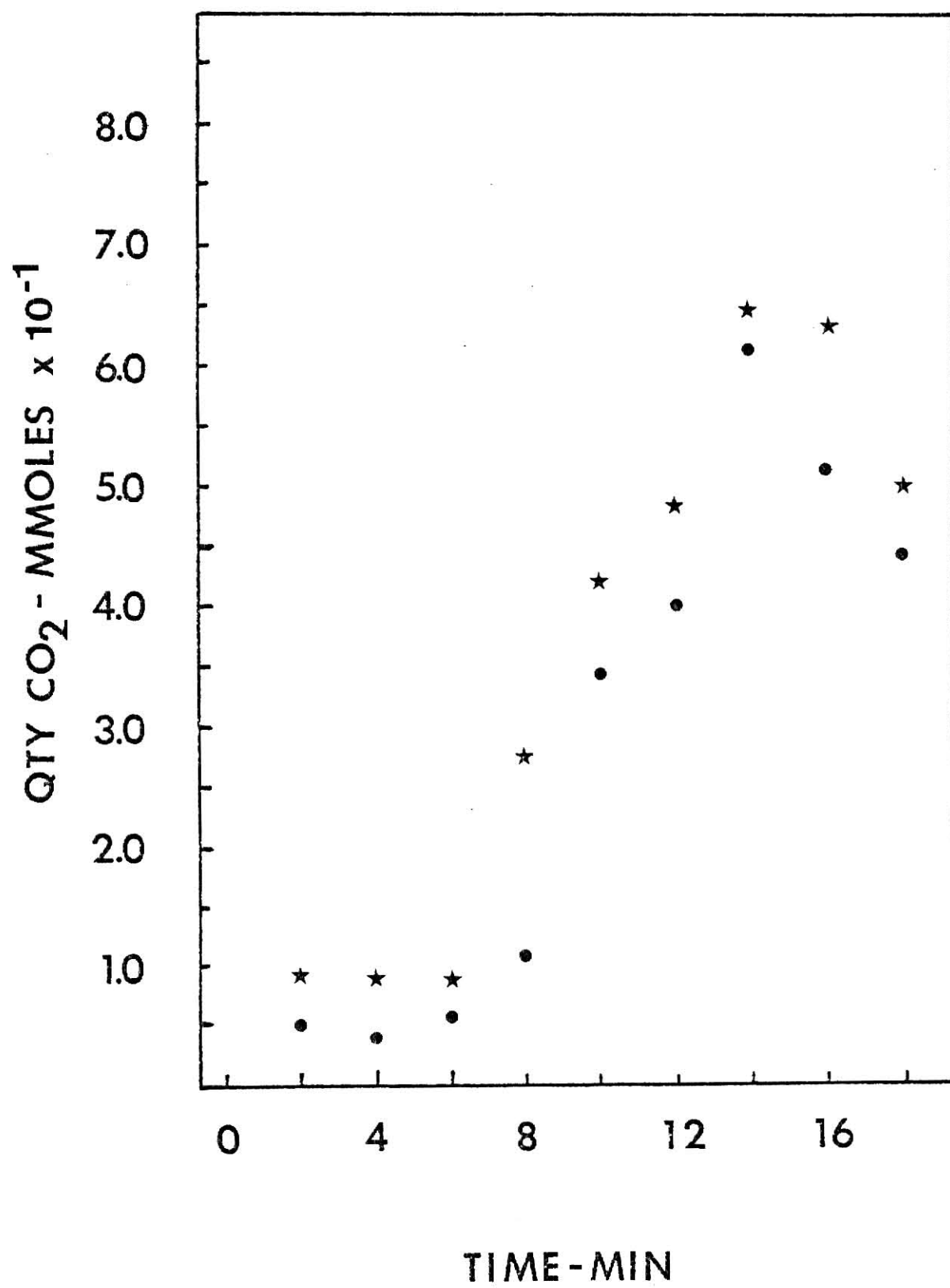


Figure 12. Release of CO₂ During Resistance Baking
vs. Time: Defatted Flour, No Shortening,
(★) and (●) represent data from different
loaves.



This data is in agreement with the work of Junge (1980) and Daniels and Fisher (1976).

SSL, also, delayed the release of carbon dioxide from the loaf during the early stage of baking much the same as the shortening loaf. SSL reduced the quantity of CO_2 released during baking compared to the no shortening loaf, particularly during the early stage of baking. However, the shortening loaf was more effective in reducing total CO_2 released than was the loaf with SSL. Most of the difference in total CO_2 released between SSL loaves and shortening loaves is accounted for in the final 10 min of baking.

The defatted flour loaves, with or without shortening, also delayed the release of carbon dioxide, but there was little difference between the shortening and no shortening loaves in time of CO_2 release nor in the quantities released during baking. This data is consistent with the findings of Pomeranz (1968) and Junge (1980) that the addition of shortening to defatted flour loaves did not affect loaf volume.

The difference in the quantity of CO_2 released during the initial 8 min of baking (approximately 0.60 mmoles) for loaves made with and without shortening represents a volume of about 15 cc at 30°C and 1 atm. This quantity of CO_2 accounts for less than 20% of the 95 cc volume difference reported by Junge (1980) for oven baked loaves made with and without shortening. This data suggests that the time of carbon dioxide release in baking has little effect on final loaf volume. Additionally, the difference in the amount of carbon dioxide retained in loaves with shortening accounts for only a small part of the difference in volume for loaves made with and without shortening.

LITERATURE CITED

- American Association of Cereal Chemists, 1980. Approved methods 22-11.
- American Association of Cereal Chemists, 1980. Approved methods 22-14.
- Bailey, C. H., 1939. Measuring fermentation rates and gas losses in dough, *Cereal Chem.* 16:665.
- Baker, J. C., and Mize, M. D., 1939. Effect of temperature on dough properties, I. *Cereal Chem.* 16:517.
- Baker, J. C., and Mize, M. D., 1939. Effect of temperature on dough properties, II. *Cereal Chem.* 16:682.
- Baker, J. C., and Mize, M. D., 1941. The origin of the gas cell in bread dough, *Cereal Chem.* 18:19.
- Baker, J. C., and Mize, M. D., 1946. Gas occlusion during dough mixing, *Cereal Chem.* 23:39.
- Bloksma, H., 1978. Rheology and Chemistry of Dough. In Wheat Chemistry and Technology, edited by Y. Pomeranz. pp. 523. AACC, St. Paul.
- Daftary, R. D., Pomeranz, Y., Shogren, M., and Finney, K. F., 1968. Functional Breadmaking Properties of Wheat Flour Lipids II. The Role of Flour Lipid Fractions in Breadmaking, *Food Tech.* 22(3):79.
- Daniels, D. G. H., and Fisher, N., 1976. Release of carbon dioxide from dough during baking, *J. Sci. Fd. Agric.* 27:351.
- Elion, E., 1933. A simple volumetric method for measuring gas production during dough fermentation, *Cereal Chem.* 10:245.
- Finney, K. F., and Barmore, M. A., 1943. Yeast Variability in Wheat Variety Test Baking. *Cereal Chem.* 20:194.
- Hibberd, G. E., and Parker, N. S., 1976. Gas pressure-volume-time relationships in fermenting doughs. I. Rate of production and solubility of carbon dioxide in dough, *Cereal Chem.* 53:338
- Hlynka, I., 1972. Some rheological aspects of yeast-leavened dough, *Baker's Digest* 46(2):44.
- Junge, R., 1980. Two effects of surfactants in bread. II. A mechanism for shortening improvement of loaf volume, p. 33. Master's Thesis, K. S. U.
- Marek, C. J., and Bushuk, W., 1967. Study of gas production and retention in doughs with a modified Brabender Oven Rise Recorder, *Cereal Chem.* 44:300.

- Mita, T., Nikai, K., Hiraoka, T., Matsuo, S., and Matsumoto, H., 1977. Physiochemical studies on wheat protein foams, J. Colloid I. Sci. 59:172.
- Mita, T., Ishida, E., and Matsumoto, H., 1978. Physiochemical studies on wheat protein foams. II. Relationship between bubble size and stability of foams prepared with gluten and gluten components, J. Colloid I. Sci. 64:143.
- Pomeranz, Y., Shogren, M., and Finney, K. F., 1968. Functional Bread Making Properties of Wheat Flour Lipids I. Reconstitution Studies and Properties of Defatted Flours, Food Tech. 22(3):76.
- Quinn, E. L., and Jones, C. L., 1936. Carbon Dioxide, p. 182. Reinhold Publishing Corp., New York, N. Y.
- Reed, G., and Peppler, H. J., 1973. Yeast Technology, p. 105. AVI Publishing, Westport, Conn.
- Rubenthaler, G. L., Finney, P. L., Demaray, D. E., and Finney, K. F., 1980. Gasograph: Design, construction, and reproducibility of a sensitive 12-channel gas recording instrument, Cereal Chem. 57:212.
- Vogel, A. I., 1978. Practical Organic Chemistry. 4th Edition, p. 788. Longman, London and New York.

ACKNOWLEDGEMENTS

I wish to express my gratitude to my major professor, Dr. R. Carl Hoseney, for his numerous suggestions, advice, and counsel during this investigation and the preparation of this thesis.

I also wish to thank Doctors Paul Seib and David Wetzel and Professor Joseph Ponte, Jr. for their service on the advisory committee.

Deep gratitude is expressed to Richard B. Koch and Deborah Rogers for their assistance and encouragement with this project.

Many sacrifices were made by my children, Adam Christopher, Amy Cathryn, and Eric Ryan, so that I could accomplish this work. I thank them for their trust.

My wife, Jenifer, made this work possible. She gave up so many things so that I might pursue my education. She gave encouragement when needed, and prodded when necessary. I am forever indebted to her for her contribution to this work.

A METHOD TO MEASURE CARBON DIOXIDE RELEASED
FROM AND CONTAINED IN YEASTED DOUGHS

by

ARTHUR RAY THACKERY

B.A., Wichita State University, 1971

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment
of the requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1982

ABSTRACT

A method is proposed to measure carbon dioxide released from and contained in yeasted doughs. A carbon dioxide electrode was used to measure quantities of carbon dioxide that had been released or contained in bread doughs. The electrode was found to be a good sensitive tool for obtaining those values.

Total carbon dioxide present in all doughs tested were similar at the end of proof. Total quantities of CO_2 released during proof were small compared to the total in the doughs for all doughs tested. There was little difference in the total amount of CO_2 released by the various doughs during proof.

CO_2 released during baking was greatest for loaves made from regular flour without shortening. More CO_2 was released from no shortening loaves during all stages of baking. Addition of shortening to regular flour doughs delayed the release of CO_2 from the loaves during baking. SSL also delayed the release of CO_2 , but was not as effective in retaining CO_2 in the loaf during the late stage of baking as was shortening. Inclusion of shortening in defatted flour loaves had little effect on CO_2 release. Defatted flour loaves did show delayed CO_2 release during baking. The total amount of CO_2 released during baking was small compared to the total amount of CO_2 present in the doughs at the end of proof, for all doughs tested. The small additional amount of CO_2 released from no shortening loaves accounts for less than 20% of volume increase achieved when shortening is included in the formulation.