THE INFLUENCE OF FORCED CONVECTION IN A ROASTING OVEN OF THE WEIGHT SHRINKAGE, FUEL CONSUMPTION AND COOKING TIME WHEN ROASTING BEEF

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By

Edward Francis Maney, Jr.

A THESIS

Submitted to the School of Graduate Studies of Michigan
State University of Agriculture and Applied Science
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ABSTRACT

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There are three methods of heat transfer, conduction, convection, and radiation. Convection is predominant in convential roasting-baking ovens. However, there are two modes of convection, natural and forced. Ovens operate principally on the former.

Engineers have recognized for a long time that the rate of heat transfer between the heat source and the object being heated is considerably increased under forced convection conditions. Within the food service industry, little work has been done in this area. Since theoretical considerations implies that utilization of the forced convection principle will influence the performance of ovens and the efficiency of roasting, the objective of this study was to utilize forced convection in a roasting oven and to measure the influence on the shrinkage, fuel consumption and cooking time when roasting beef.

Control factors were determined by roasting beef under natural convection conditions at various oven temperatures. The experimental data was then taken by cooking similar roasts under forced convection conditions at various oven temperatures and at various air velocities.

The results show that forced convection in roasting-baking ovens does influence the weight shrinkage, fuel consumption and cooking time when roasting beef and that optimum conditions

prevailed in the region 275 degrees Fahrenheit oven temperature with an air velocity of 769 feet per minute. When the results achieved at this air velocity and temperature are compared with the results obtained in a conventional, natural convection oven at 350 degrees Fahrenheit, it was found that there was on an average:

a) a decrease in cooking time of 2.48 minutes per pound,

b) a decrease in volatile loss of 2.08 percent,

c) a decrease in drip loss of 3.15 percent,

d) a decrease in shrinkage of 5.23 percent, and

e) an increase in fuel consumption of 0.17 kilowatt hours.

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INTRODUCTION

There are three methods of heat transfer, conduction, convection and radiation. Conduction is the movement of heat from a warm body to a cooler body when the two bodies are in contact with each other. Convection is the transfer of heat between a moving fluid medium, such as gas, air or fat, and a heat surface. It is also the transfer of heat from one point to another within the fluid by movements within the fluid. Radiation is heat which passes from a higher temperature without necessarily heating the space in between.

Convection can occur by two methods, natural and forced. When a fluid, such as air, is heated, it expands. The heated portion rises while the cooler denser air moves downward. This is known as natural convection. If a mechanical apparatus, such as a fan or blower, is used to move this fluid then it is called forced convection.

Natural convection is the condition under which a conventional roasting-baking oven common to the restaurant industry, whether gas, oil, coal or electrically heated, ordinarily operates. These are heated enclosures wherein heat is transferred from the heat source to air which in turn heats the product.

Newton's law of heating and cooling states that the rate of heat transfer is directly proportional to the difference in temperature of the two substances. However, heat transfer is hindered by a layer of stagnant air known as a laminar layer which surrounds the object being heated; the greater the thickness of this layer, the longer it takes heat to transfer from the source to the object.

In accordance with heat transfer laws the rate of heat transfer for the same temperature differential in greater under forced convection than under natural convection because forced convection tends to reduce the laminar layer of air. Engineers have known this for a long time. However, prior to June 1960, there is relatively little evidence that work had been accomplished in applying principles of forced convection to conventional roasting-baking ovens.[1]

Since little work has been accomplished in this area and since that heat transfer rate can be increased by increasing the air velocity, the following hypotheses were made. (A) The cooking rate should increase with an increase in air velocities. Therefore, less cooking time should be required. (B) A reduction in cooking time should result in a corresponding reduction in fuel consumption. (C) At any given temperature, a reduction in cooking time should result in less shrinkage.

The purpose of this study was to investigate the validity of these hypotheses.

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[1]The research on this study was concluded June 1, 1960.

REVIEW OF LITERATURE

A search of literature pertaining to forced convection in the Food Service Industry shows a lack of writing in this area. It was, therefore, necessary to turn to the engineering profession for this information.

Croft (3) Brown and Marco (2) Jacob (10) Manly (11) Henderson and Perry (9) Giedt (7) Worthing and Holliday (12) all point out that there are three different ways in which heat is transferred; conduction, convection and radiation. However, Croft (3) points out that the conveyance of heat from one body to another may occur simultaneously by any two or all three of these methods. A description of each of these methods follows.

Conduction: Croft (3) and Brown and Marco (2) point out that there are two means by which conduction can occur. One is referred to as external conduction while the second is identified as internal conduction.

Croft (3) refers to external conduction as heat which is transmitted from the molecules of a warm body to the molecules of cooler body when the two bodies are in contact with one another.

Internal conduction, as Brown and Marco (2) state it, is heat that is transmitted from molecules in a high temperature region to molecules in a low temperature region within a homogeneous substance. This action is without discontinuity and with a continuous fall of temperature from the high to low region (i.e., the heat traveling from the outer surface of a roast toward the center of a roast.).

Convection: Manly (11) states if air or water, or any other gas or liquid, is in contact with a solid surface whose temperature is relatively high, heat will pass by conduction from the warm surface into the air or water. While this is being accomplished, the heated portions of the fluids tend to rise, because a change in density makes the heavier cooler portions fall and push the lighter ones upward. Motion of a fluid when heat causes a difference in density of different portions, and because of the resulting effect of this situation or changing state, is called convection.

Convection, like conduction, as emphasized by Croft (3) and Brown and Marco (2) also has two major classifications, natural and forced.

Natural convection, Croft (3) points out, is the transfer of heat by the moving fluid medium and a surface within the fluid body. When a fluid, such as air is heated, it expands. Since this causes the density of the heated portion to become lower than the surrounding air, this heated portion will rise and be replaced by a cooler mass of air. This mass, likewise becomes heated and displaced. Continuous circulating currents are thus set up in the fluid. When this movement of air is produced by mechanical means such as a fan or pump, Brown and Marco (2) refer to it as being transmitted by forced convection.

However, it must be remembered, as Jacob (10) points out, that heat convection without conduction does not occur. Convection brings warmer parts of a fluid in contact with cooler ones, causing conduction.

Radiation: Brown and Marco (2) refer to heat which passes from a higher temperature body through space to bodies at lower temperatures some distance away without warming the medium in between, as being transferred by radiation. It operates by virtue of electromagnetic wave motion essentially the same as that employed in a microwave oven, or the passage of the sun's heat to the earth.

Resistance to Heat Transfer: Henderson and Perry (9) relate that the resistance to the heat ransfer principal is caused by a relatively stagnant layer and an adjacent turbulent zone of fluid at the solid-fluid interface. Conductance can be increased by reducing the thickness of the laminar layer of fluid by more agitation than is present in natural convection alone.

This solid fluid interface is shown diagrammatically in Figure 1, Page 6, where the flow of air over a surface is divided into three regions. In a very thin layer of air near the wall (O to A), viscous forces predominate and the fluid layer is laminar. Next to this layer is a region in which the motion is either streamlined or turbulent at any instant (A to B); it serves as a transition region or buffer layer between the laminar sublayer and the fully developed turbulent region (above B).

Brown and Marco (2) further emphasize that at very low velocities and at a constant temperature each particle of the fluid moves in a path substantially parallel to the path followed by all other particles, and the flow is described as laminar. This does not mean that each particle moves at the same velocity as every other particle but simply that all particles travel in parallel directional paths.

When the flow of the fluid is increased beyond a certain critical velocity, laminar flow can no longer continue and turbulent flow predominates. In the range of turbulent flow innumerable eddy and cross currents occur.

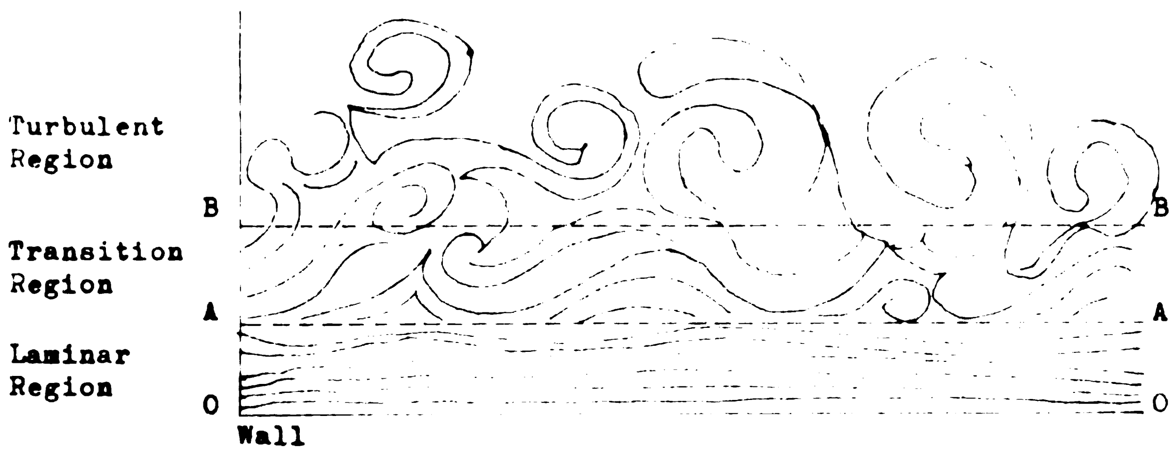


Figure 1.

THE THREE REGIONS OF A TURBULENT

BOUNDARY LAYER

Giedt (7)

This critical velocity for any temperature-velocity combination may result in a peculiarity occurring in the slope of the curve. In this instance, rather than the temperature being constant and the velocity being the variable, the opposite is true--the temperature is the variable and the velocity is the constant.

The transition that occurs at the critical velocity from streamlined to turbulent flow is neither instantaneous nor positively fixed. As a result there is an appreciable overlapping of the highest velocity for laminar (streamlined) flow and the lowest velocity at which turbulent flow may occur.

No attempt is ordinarily made to measure the thickness of this laminar film. The film may be immeasurably thin or several hundredths of an inch in thickness, but in the study of heat transfer it may be visualized as a barrier to the flow of heat.

Although conductance can be increased by reducing the thickness of the laminar film, Dersch (5) relates that heat transfer by forced air convection decreases as the diameter of the item around which the air flows is increased. Therefore, the smaller the product, within certain limitations, the greater the heat transfer achieved. Dersch (5) further states that heat transfer by forced convection is 7.5 to 19.6 per cent higher for curved surfaces than for plane surfaces; 8 per cent less for items inclined 45 degrees; and increases as the surfaces roughness increases.

Henderson and Perry (9) also add that the amount of turbulence decreases as the distance from the fan is increased and will also vary depending on the viscosity of the fluid.

Further restrictions that will alter the cooking time required are pointed out by Dawson, Linton, Harkin and Miller (4). These factors are: (a) cooking methods, (b) juiciness as related to fat content, (c) internal temperature to which the meat is cooked, (d) time cooked in an uncovered pan, (e) shape and thickness of the roast, and (f) the grade of the meat.

Fitch and Francis (6) mention that the amount of connective tissue and the length of aging will also effect the cooking time, as will the composition of the meat and the temperature of the roast at the beginning of the cooking period.

In addition, Lowe (11) emphasizes that the following factors will affect the time required to cook meat; (a) the cooking temperature; and (b) weight, surface area, and the shortest distance to the thickest portion of the meat.

In the area of food service, Dersch (5) mentions that the baking industry was the first to utilize forced convection by employing steam jets in a tunnel oven for the sole purpose of creating air turbulence within the baking chamber. About fifteen years ago, the first duct-type agitator made its appearance. The fans in these agitators would discharge from 1500 to 2000 cubic feet of air per minute at localized spots in the oven. However, little effect was realized. The next attempt to provide agitation took the form of a series of centrifugal blowers driven by an external motor. If nothing else, these wheels served to give good lateral distribution of temperature.

However, Lough (11) in his <u>Study of the Effect of Air Velocity and Temperature on Defrosting Ground Beef</u> found forced convection definitely increased the defrosting rate. An optimum velocity for his study was found to be between 350 and 400 feet per minute.

Nothing appeared again in literature until Hampel (8) mentions that the Research Engineer Laboratories of the American Gas Association, Incorporated, had been experimenting with forced convection since 1955. In May, 1959, the results of this research were partially responsible for the introduction of a gas-operated, forced convect on oven sold under the trademark of the Wimco Oven.

During this same period preliminary work in the use of forced convection was conducted by Borsenik and Newcomer (1) of the Food Service Industry Research Center at Michigan State University, East Lansing, Michigan. Meat loaves were used as the specimen in their experimentation. The results indicated that under forced convection total cooking time at 350 degrees Fahrenheit was 66.8 minutes, while under natural convection 107 minutes were required. Fuel consumption at this temperature was 1.0 kilowatt-hours for forced convection whereas for natural convection it was 1.3 kilowatt-hours. An even greater reduction in fuel consumption was experienced when the temperature under forced convection was dropped to 250 degrees Fahrenheit; this was found to be 0.7 kilowatt-hours or 48 percent less than at 350 degrees Fahrenheit. Considering this drop in temperature, cooking time still remained substantially the same when compared to the time required at 350 degrees under natural convection. Forced convection also was found to influence shrinkage. Under natural convection it was reported to be 22.3 percent while under forced convection it was found to be 21.6 percent.

Dersch (5) states that there has been much discussion about forced versus natural convection as a method of heat distribution in roasting-baking ovens. About the only point of general agreement is that air agitation is influencial. However, there has been little agreement on the extent of agitation (i.e., flow rate) and the influence on fuel consumption, shrinkage and cooking rate.

In the use of forced convection, Dersch (5) also mentions that for any given temperature there is a correspondingly optimum volume of air which will transfer the maximum amount of Btu's from the heat source to the product. Increasing the volume of air beyond this point will not increase the transfer of heat.

STATEMENT OF THE PROBLEM

From an engineering standpoint, it is realized that the rate of heat transfer for the same temperature differential is greater under forced convection than under natural convection. Literature pertaining to this subject shows that this area has not been fully investigated in its application to roasting-baking ovens.

OBJECTIVES

The object of this study is to measure the influence of forced convection in a roasting oven on weight shrinkage, fuel consumption and cooking time when roasting beef.

APPARATUS

The Experimental Oven: As shown in Figure 2, Page 16, the oven used in this study was a conventional, electrically-heated oven modified by the addition of an electric, motor-driven fan. The apparatus consists of an enclosure (A) with internal demensions of 26½ inches long, 18¼ inches wide and 14¼ inches high. Heat was provided by two heating elements (B) located at the base and running horizontally along the side walls with an electrical rating of 115 volts and 1600 watts.

A 10-inch, 3-blade, propeller-type fan (C) around which a shroud (D) 12-inch in diameter and 6-inches wide was secured, was mounted on a shaft driven by a ½ horsepower, 1725 R.P.M. motor (E) Figure 3, Page 17. Four, 4-step pulleys (F) were affixed to the motor shaft and the fan shaft which were driven by a "V" belt (G).

Measurement of Air Velocity: The Velocity of air was measured with a Davis Instrument Manufacturing Company Anemometer, Figure 4, Page 18, for different combinations of the step pulleys. The results are shown in Table 1, Page 21. Velocities ranging from 350 feet per minute to 2500 feet per minute were recorded at one foot from the fan blade.

The Roasting Pan: All roasts were prepared in a stainless steel pan, Figure 5, Page 19, 16 inches long, 11-inches wide and 1-inch deep. Roasts were placed in the pan on a wire rack approximately one half inch from the base. This permitted more surface area exposure to the flow of air and also aided in the collection of drip loss.

Recording of Temperatures: Temperatures were measured in three regions: the oven temperature, the surface temperature of the roast, and in the center of the roast. Thermocouples were placed in each of these areas while the opposite ends were connected to a Minneapolis-Honeywell, Brown Electronic, Potentiometer, which indicated and recorded temperatures. The accuracy of this instrument is within plus or minus four degrees Fahrenheit over the 0 to 600 Fahrenheit degree range and within plus or minus one degree Fahrenheit between room temperature and 400 degrees Fahrenheit.

The temperature settings of thermostat dials of commercials ovens often do not agree with the actual temperature in the oven. Consequently, oven temperatures were manually controlled and the actual oven temperatures were recorded on the potentiometer.

Measurement of Fuel Consumption: Total fuel consumption was determined by ascertaining both the quantity of electrical power to the motor at different speeds and the quantity of electrical power to the oven. Figure 6, Page 20, shows the electric watt-hour meter (H), which indicates, by the speed of the disk, the electrical load.

Electric power to the heating elements was determined by correlating the speed of the watt-hour disk with the oven in operation against the speed of this disk using a 2000 watt light bank. Figure 6, Page 20, also shows a clock (I) controlled by a tripswitch (J) which automatically measure the time the heat elements received electrical power. By measuring the power consumption rate and the total time the power was applied, the total power consumption could be calculated.

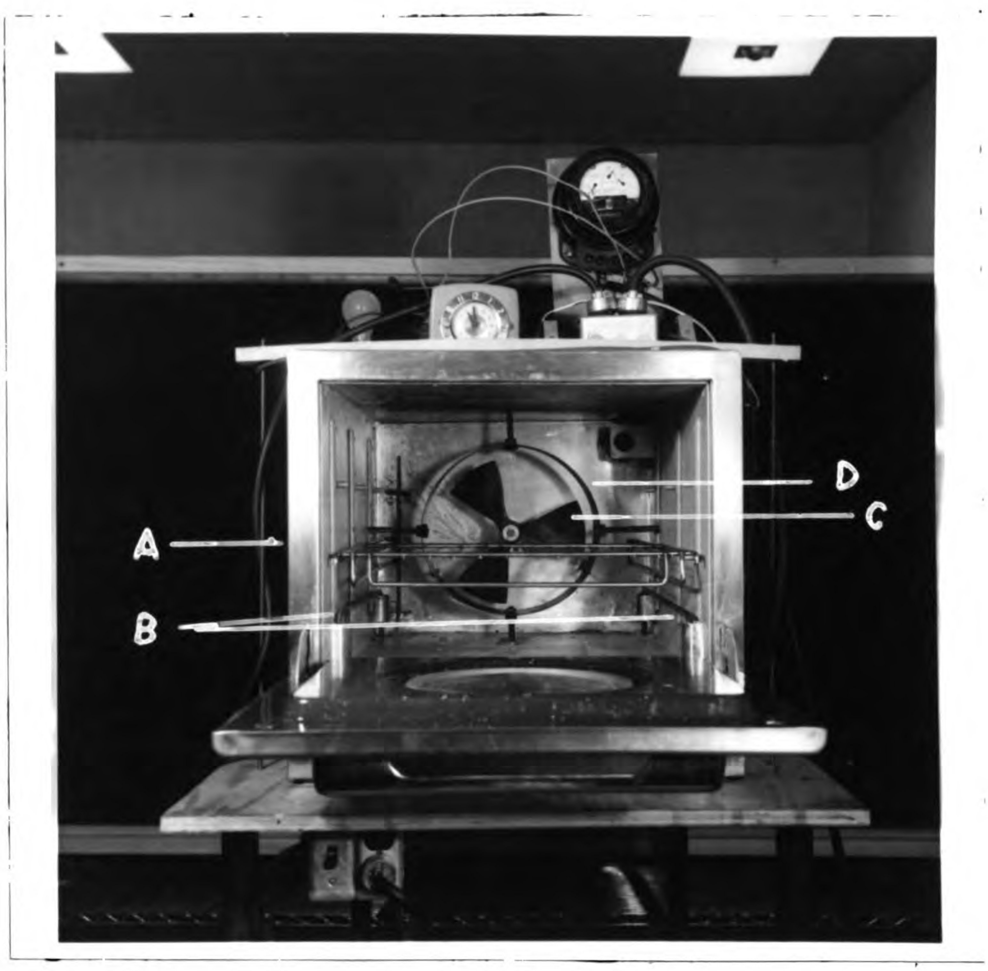


Figure 2. The experimental oven

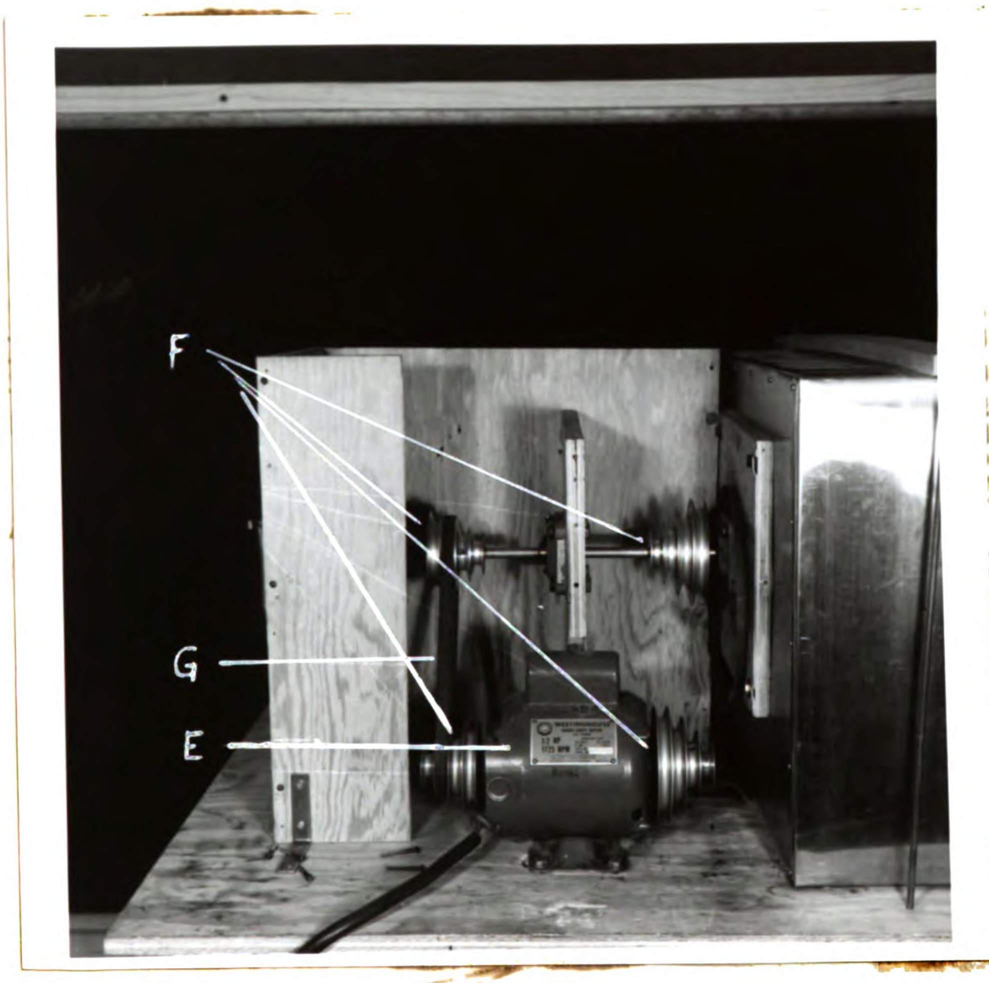


Figure 3. The motor, step-pulleys, shaft and belt

Figure 4. The anemometer

Figure 5. The roasting pan, wire rack and specimen

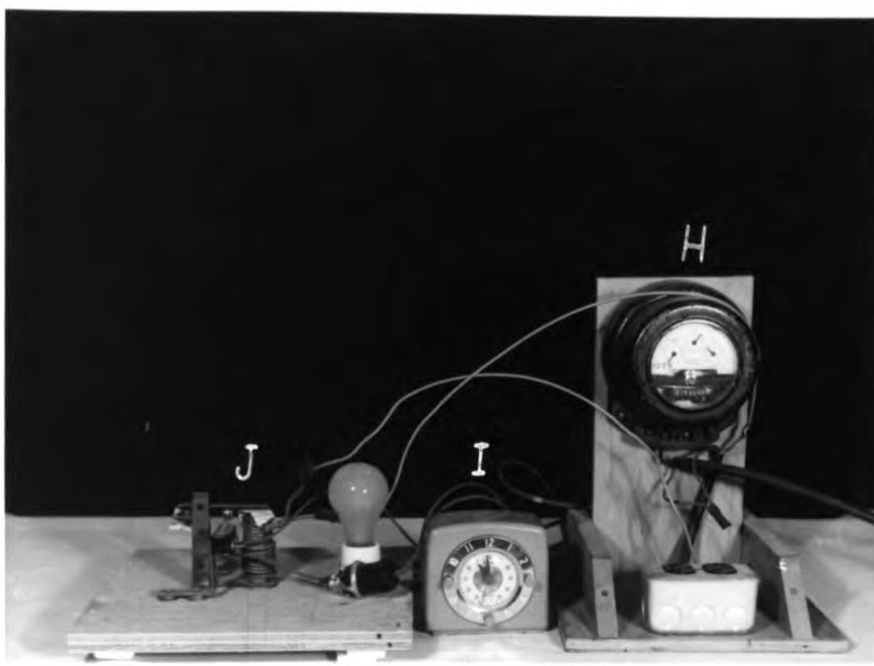


Figure 6. The electric watt-hour meter, clock and switch.

Table [illegible]. Air velocities at various pulley combinations

Pulley Sizes		Movement of Air *		Air Velocities	
Diameter of Driver	Diameter of Driven	Distance in Feet	Time in Minutes	Feet per Minute	Miles per Hour
2.0"	5.0"	200	.570	350.9	4.00
2.0"	4.0"	200	.400	500.0	5.70
3.0"	4.0"	200	.280	714.3	8.14
2.5"	3.5"	200	.260	769.0	8.77
3.5"	2.5"	400	.300	1333.0	15.22
4.0"	3.0"	400	.275	1454.5	16.58
4.0"	2.0"	400	.200	2000.0	22.80
5.0"	2.0"	800	.320	2500.0	28.50

*Determined by the anemometer located half way between the oven door and the fan blade.

PROCEDURE

Two major steps, preparation of the roast and roasting under conditions of natural convection, were necessary in determining the effect forced convection would have on the shrinkage, fuel consumption and cooking time of roasted beef. Determination of an optimum air velocity and an optimum cooking temperature resulted from an analysis of the information under conditions of forced convection.

Preparation of Roasts: All specimens were U.S. Choice, unfrozen, six-pound, paired, top round roasts. All roasts were refrigerated overnight at 33 to 35 degrees Fahrenheit for no longer than 24 hours. This was done to insure approximately the same center temperature at the beginning of the roasting period. As near as possible, consistency in size and shape were achieved by trimming all paired roasts to five pounds. The weight of each roast was recorded to within one-eighth ounce on a Toledo Scale, Model 4031-V.

Although the grade and cut of meat were controlled, the amount of connective tissue, composition, length of aging and juiciness as related to fat content could not be controlled.

Prior to roasting, recordings were made of the weight, center temperature and surface temperature of the product and the combined weight of the pan and wire rack.

A thermocouple was inserted into the center of the roast and attached to the surface of the roast. The roasts were then placed on a rack, in a pan, as shown in Figure 5, page 19, and inserted into the oven half way between the face of the fan and the oven door with the vertical side of each roast nearest the fan.

When a center temperature of a 160 degrees Fahrenheit was obtained on all roasts recordings were made of the cooking time, finished weight and fuel consumption. Since the beginning weight of each roast was known it was possible to ascertain the drip loss by removing the roast and rack from the pan and weighing the liquid in the pan. Volatile loss was calculated as the difference between the weight of the raw roast and the cooked weight of the roast plus the drippings.

This study included fifteen roasting tests with two replications of each test. One exception occurred where only one replication was used.

Roasting Under Natural Convection: The results under natural convection conditions were used as a control. Three roasts, cooked separately, were roasted at temperatures of 200, 250, 275, 300 and 350 degrees Fahrenheit to a center temperature of 160 degrees Fahrenheit. An exception occurred in the case of those roasts cooked at 200 degrees Fahrenheit.

Determination of an Optimum Velocity: Air velocities of 350, 500, 769, 1333 and 2000 feet per minute were selected from velocities ranging from 350 to 2500 feet per minute (Table 1, page 21). These velocities were tested to determine if an optimum velocity fell within this range. Three roasts were again cooked at each of these velocities.

DATA AND RESULTS

Table 2, page 25, presents the control data; an analysis of the results when beef is roasted by natural convection. In the formulation of this data three roasts were cooked at each of the following temperatures: 200, 250, 300, 350 and 400 degrees Fahrenheit. All roasts were cooked to a center temperature of 160 degrees Fahrenheit except those roasts cooked at 200 degrees Fahrenheit where only a center temperature of 156 degrees Fahrenheit could be achieved; thus the reason for the notation "incomplete".

The time-temperature relationship of roasting beef under natural convection, as shown in Figure 7, page 26, shows a sharp decrease in required cooking time between the 200 to 300 degrees Fahrenheit cooking range. Viewing these points as a continuous curve rather than as lines from point to point, the curve remains substantially vertical between 200 degrees to 275 degrees Fahrenheit. Between 275 degrees and 400 degrees Fahrenheit the curve is more horizontal in nature. It was then decided to use 275 degrees as the constant temperature.

In viewing this time-temperature relationship it will be noted that under forced convection a peculiarity in the slope of the curve appeared between 275 degrees and 300 degrees Fahrenheit. This may be due to what Brown and Marco (2) refer to as the "critical velocity" for any given temperature-velocity combination.

Figure 8, page 27, shows the relationship between air velocities of 350, 500, 769, 1333 and 2000 feet per minute, and cooking

Table 2. Total shrinkage, volatile and drip loss -- cooking time -- oven fuel consumption of U.S. choice top round roasts at various temperatures under natural convection

Temperature (°F)	Cooking Time per pound (minutes)	Volatile loss (%)	Drip loss (%)	Total Shrinkage (%)	Oven Fuel Consumption (KWH)
*200	111.69	17.61	6.92	24.53	1.70
"	112.76	16.52	6.66	23.18	1.74
average	112.30	17.06	6.79	23.86	1.72
250	55.40	15.94	6.24	22.18	1.61
"	65.81	20.45	7.85	28.30	1.93
"	61.78	18.56	6.29	24.85	2.11
"	60.35	17.42	7.89	25.31	1.70
average	60.84	18.09	7.07	25.16	1.84
300	42.60	19.38	6.24	25.62	1.97
"	40.00	18.76	5.62	24.38	1.84
"	43.40	19.86	8.12	27.98	1.97
average	42.00	19.33	6.66	25.99	1.93
350	30.23	18.21	6.19	24.40	2.04
"	32.80	17.71	6.20	23.91	2.29
"	33.00	20.32	6.26	26.58	2.20
average	32.01	18.75	6.22	24.96	2.18
400	31.00	25.16	4.54	29.70	2.29
"	26.08	26.18	5.17	31.35	2.45
"	29.24	25.56	7.66	33.22	2.38
average	28.77	25.63	5.79	31.42	2.37

*incomplete

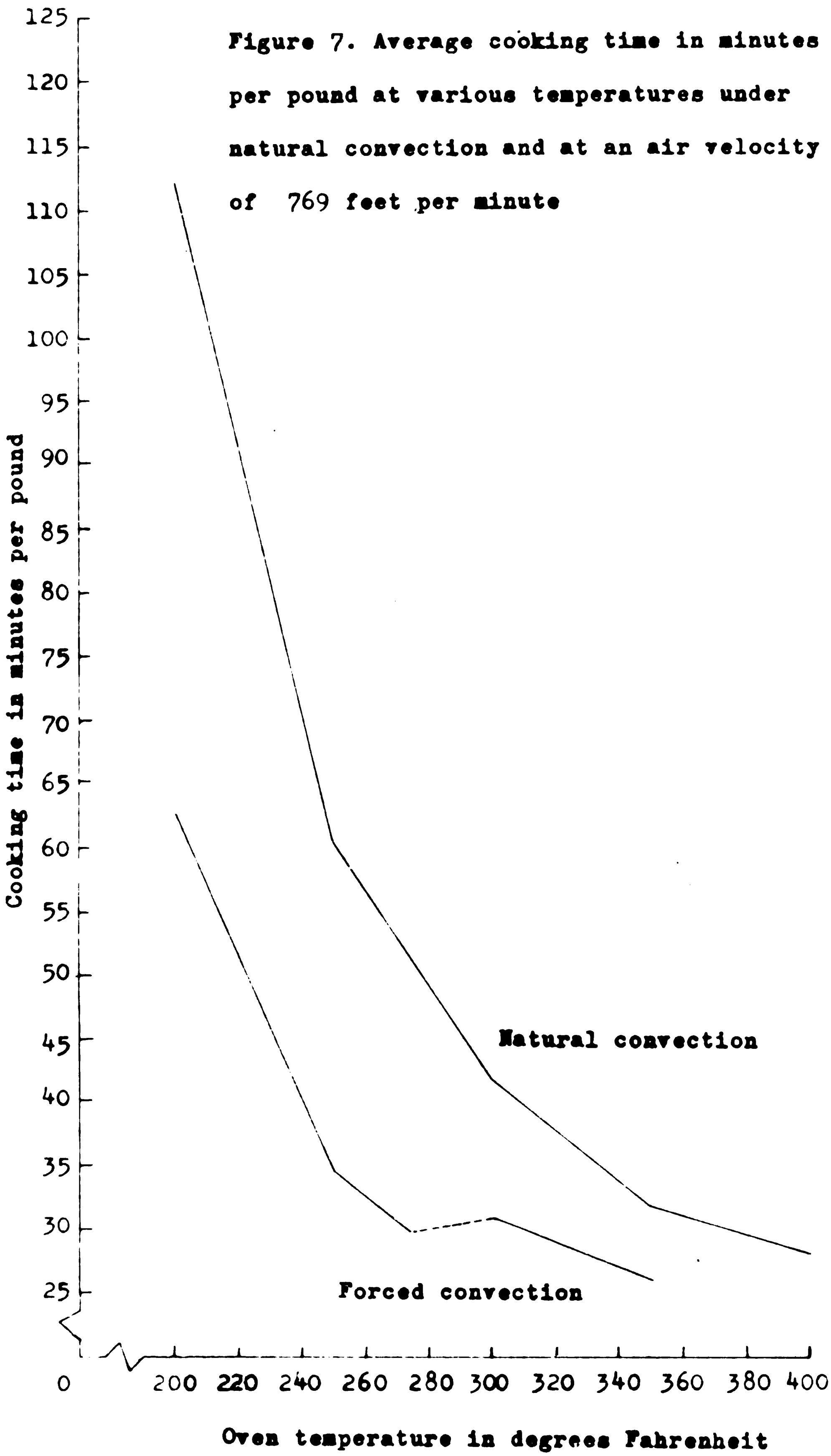


Figure 7. Average cooking time in minutes per pound at various temperatures under natural convection and at an air velocity of 769 feet per minute

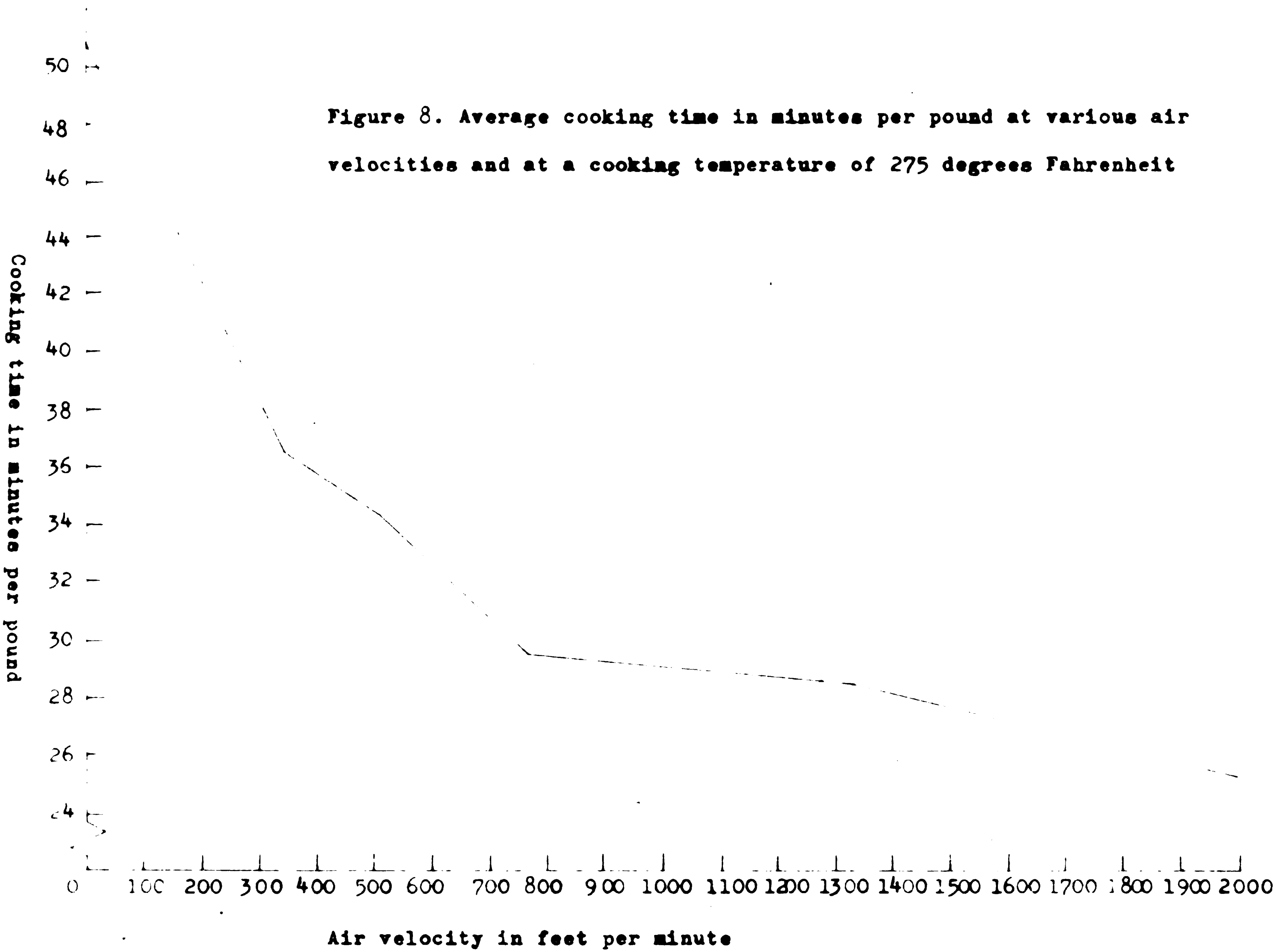


Figure 8. Average cooking time in minutes per pound at various air velocities and at a cooking temperature of 275 degrees Fahrenheit

time while holding the oven temperature constant at 275 degrees Fahrenheit. Here again a sharp decrease in cooking time is evident from 0 to 769 feet per minute. Beyond this point the cooking time is reduced but at a decreased rate; thus the reason for using 769 feet per minute as the optimum air velocity.

The temperatures observed under forced convection at 769 feet per minute ranged from 200 degrees Fahrenheit to 350 degrees Fahrenheit. Sufficient charring of the surface of the roast occurred at 350 degrees to warrant terminating the work at this temperature.

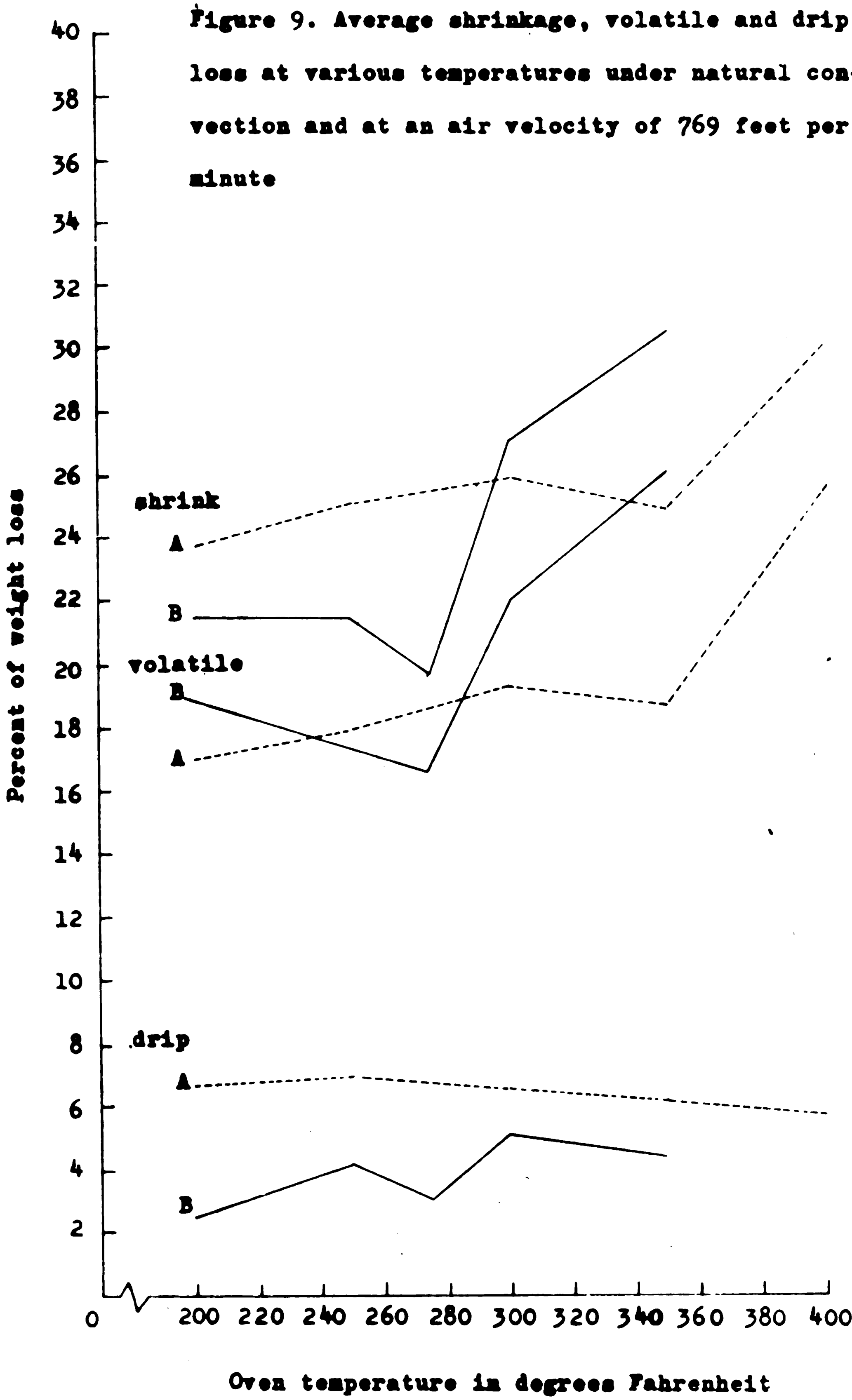
Observation of the data relating to total shrinkage, volatile and drip loss, as indicated in Table 2, page 25, and Table 3, page 29, shows that these factors are at their lowest when the meat was roasted under forced convection at 275 degrees Fahrenheit. Figure 9, page 30, presents this information in graphic form.

Using cooking time as a means of comparison it can be noted that, given a constant cooking time, the same results would be achieved by roasting at 275 degrees Fahrenheit and an air velocity of 769 feet per minute as achieved when roasting at 390 degrees Fahrenheit under natural convection. Similarly, 263 degrees Fahrenheit at the same air velocity is equivalent to roasting at 350 degrees Fahrenheit under natural convection. Beyond this temperature percent-loss tends to increase rapidly. At 350 degrees Fahrenheit forced convection volatile-loss is 7.35 percent greater and shrinkage is 5.57 percent greater than roasts cooked at the same temperature under natural convection.

Table 3. Total shrinkage, volatile and drip loss -- cooking time -- oven and motor fuel Consumption of U.S. choice top round roasts at various temperatures and at a constant air velocity of 769 feet per minute

Temperature (°F)	Time per pound (minutes)	Volatile loss (%)	Drip loss (%)	Total Shrinkage (%)	Oven Fuel Consumption (KWH)	Motor Fuel Consumption (KWH)	Total Fuel Consumption (KWH)
200	63.60	19.24	3.10	22.34	1.40	1.63	3.03
"	67.60	21.56	2.20	23.76	1.34	1.73	3.08
"	56.80	15.94	2.50	18.44	1.38	1.46	2.83
average	62.67	18.91	2.60	21.51	1.37	1.61	2.98
250	37.20	17.20	3.28	20.48	1.61	.95	2.57
"	36.80	20.00	5.94	25.94	1.79	.95	2.73
"	30.20	14.70	3.12	17.82	1.49	.78	2.26
average	34.73	17.30	4.11	21.41	1.63	.89	2.52
275	29.40	20.62	2.04	22.66	1.65	.75	2.40
"	30.20	14.24	2.96	17.20	1.52	.78	2.30
"	29.00	15.16	4.22	19.38	1.61	.75	2.36
average	29.53	16.67	3.07	19.75	1.59	.76	2.35
300	30.60	20.00	5.48	25.48	1.97	.79	2.75
"	30.40	21.40	5.34	26.74	1.92	.78	2.69
"	32.60	24.54	4.54	29.08	2.38	.84	3.22
average	31.20	21.98	5.12	27.10	2.09	.80	2.89
350	28.20	28.44	4.06	32.50	2.56	.72	3.28
"	26.80	27.04	4.22	31.26	2.42	.69	3.10
"	25.40	22.82	5.00	27.82	2.24	.65	2.89
average	26.80	26.10	4.40	30.53	2.40	.69	3.09

Figure 9. Average shrinkage, volatile and drip loss at various temperatures under natural convection and at an air velocity of 769 feet per minute



A - indicates natural convection
B - indicates forced convection

Since roasting in a normal oven is usually accomplished at 350 degrees, and the forced convection data indicates an optimum cooking temperature at 275 degrees, a comparison of losses at these two temperatures produced the following results.

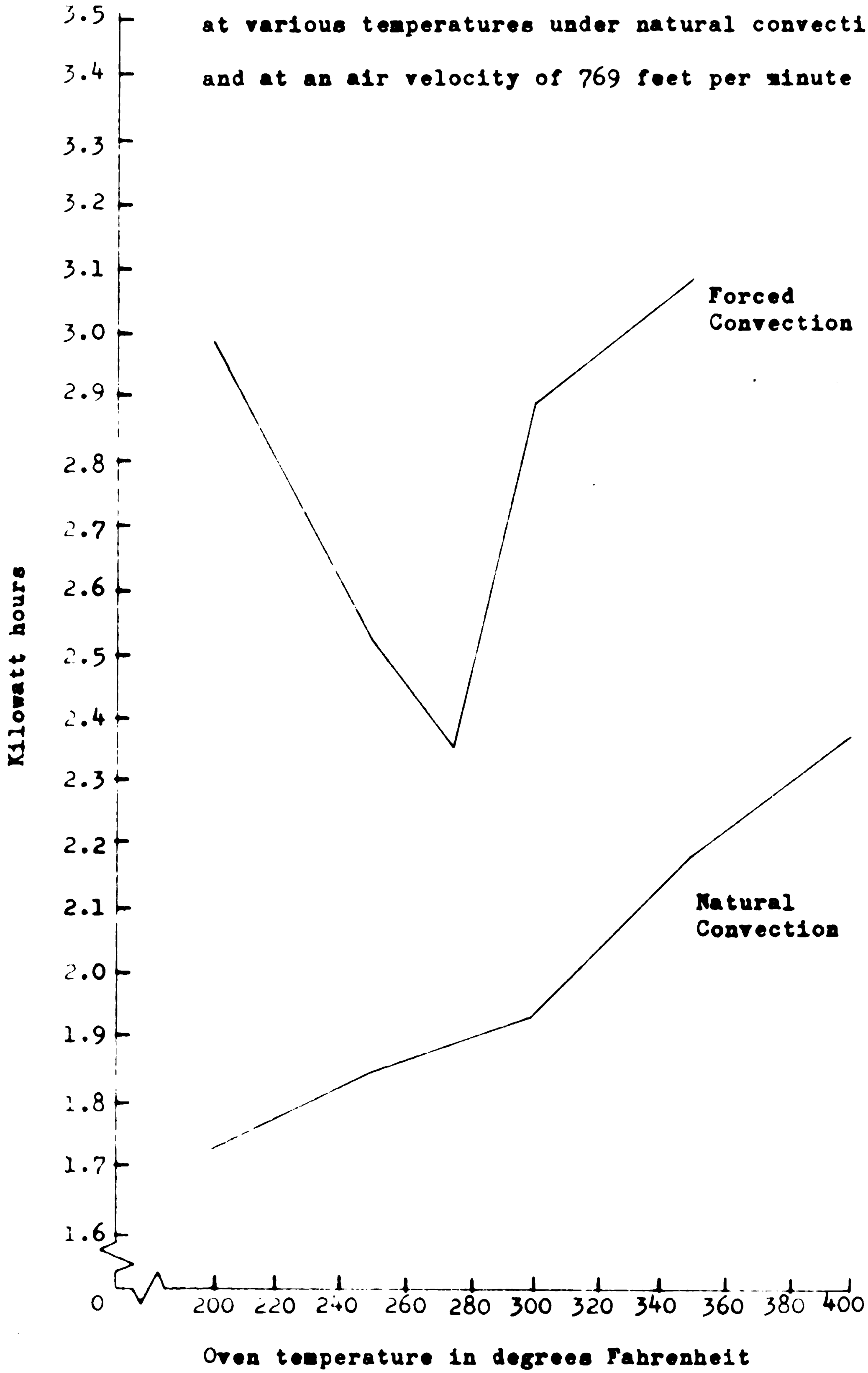
Table 4. Comparison and difference between 350 degrees Fahrenheit under natural convection and 275 degrees Fahrenheit at an air velocity of 769 feet per minute

	350°F	275°F	Difference
Cooking time in mins. per pound	32.01	29.53	2.48
Drip loss %	6.22	3.07	3.15
Volatile loss %	18.75	16.67	2.08
Shrink loss %	24.96	19.75	5.23
Fuel consumption in KWH	2.18	2.35	.17

In every instance, with the exception of fuel consumption, savings can be achieved by cooking at 275 degrees under forced convection as compared with natural convection at 350 degrees Fahrenheit.

Figure 10, page 32, is a graph of the fuel consumption. Total consumption was determined by the summation of both the oven and motor fuel consumption. Again, fuel consumption is at a minimum at 275 degrees Fahrenheit. Table 2, page 25, presents a breakdown of fuel consumption for the oven at various temperatures, while Table 3, page 29, shows fuel consumption of the oven and motor at a constant air velocity of 769 feet per minute.

Figure 10. Average fuel consumption of oven at various temperatures under natural convection and at an air velocity of 769 feet per minute



Total shrinkage, volatile and drip loss also support the statement that 769 feet per minute is an optimum velocity for it was at this velocity where the greatest savings were achieved. Table 5, page 34, and Figure 11, page 35, show the results of these tests. Here again it will be noted that a decrease is evident up to 769 feet per minute. From there on, the curve reverses its slope and the optimum velocity has been achieved.

Fuel consumption of any temperature studied was at a minimum at 275 degrees Fahrenheit and at an air velocity of 769 feet per minute. Figure 12, page 36, and Table 5, page 34, present the data which shows a separate consumption for both the motor and oven. Only in one instance was greater savings achieved at an air velocity other than 769 feet per minute and this was at 2000 feet per minute. However, the fuel consumption of the motor increased to such an extent that this lower consumption has little effect on the combined motor-oven fuel consumption as is also shown in Figure 12, page 36.

Table 5. Total shrinkage, volatile and drip loss -- cooking time -- oven and motor fuel consumption of U.S. choice top round roasts at various air velocities with temperature constant at 275 degrees Fahrenheit

Air Velocity (Feet per minute)	Cooking Time per Pound (Minutes)	Volatile Loss (%)	Drip Loss (%)	Total Shrinkage (%)	Oven Fuel Consumption (KWH)	Motor Fuel Consumption (KWH)	Total Fuel Consumption (KWH)
350	33.4	18.44	5.64	24.08	.79	1.84	2.63
"	39.0	18.60	10.00	28.60	.92	1.52	2.44
"	36.8	23.12	3.76	26.88	.87	1.61	2.48
average	36.4	20.05	6.47	26.52	.86	1.66	2.52
500	34.0	19.38	3.74	23.12	.83	1.79	2.62
"	31.8	14.24	5.46	19.70	.78	1.49	2.27
"	37.4	16.26	7.82	24.08	.91	1.65	2.56
"	34.8	16.88	5.62	22.50	.85	1.79	2.64
average	34.5	16.69	5.66	22.35	.84	1.68	2.52
769	29.4	20.62	2.04	22.66	.75	1.65	2.40
"	30.2	14.24	2.96	17.20	.78	1.52	2.30
"	29.0	15.16	4.22	19.38	.75	1.61	2.36
average	29.5	16.67	3.07	19.75	.76	1.59	2.35
1333	30.3	22.67	1.83	24.50	.97	1.93	2.90
"	24.0	14.08	4.68	18.76	.82	1.52	2.34
"	28.8	21.40	3.46	24.86	.98	2.00	2.98
"	27.6	20.62	3.14	23.76	.94	1.65	2.59
"	32.0	22.18	3.30	25.48	1.09	1.93	3.02
average	28.5	20.19	3.28	23.47	.96	1.81	2.77
2000	25.6	22.18	2.82	15.00	1.56	1.52	3.08
"	25.4	20.00	5.78	25.78	1.55	1.47	3.02
"	25.0	18.76	5.48	24.24	1.52	1.38	2.90
average	25.3	20.31	4.69	25.01	1.54	1.46	3.00

Figure 11. Average shrinkage, volatile and drip loss at various air velocities and at a cooking temperature of 275 degrees Fahrenheit

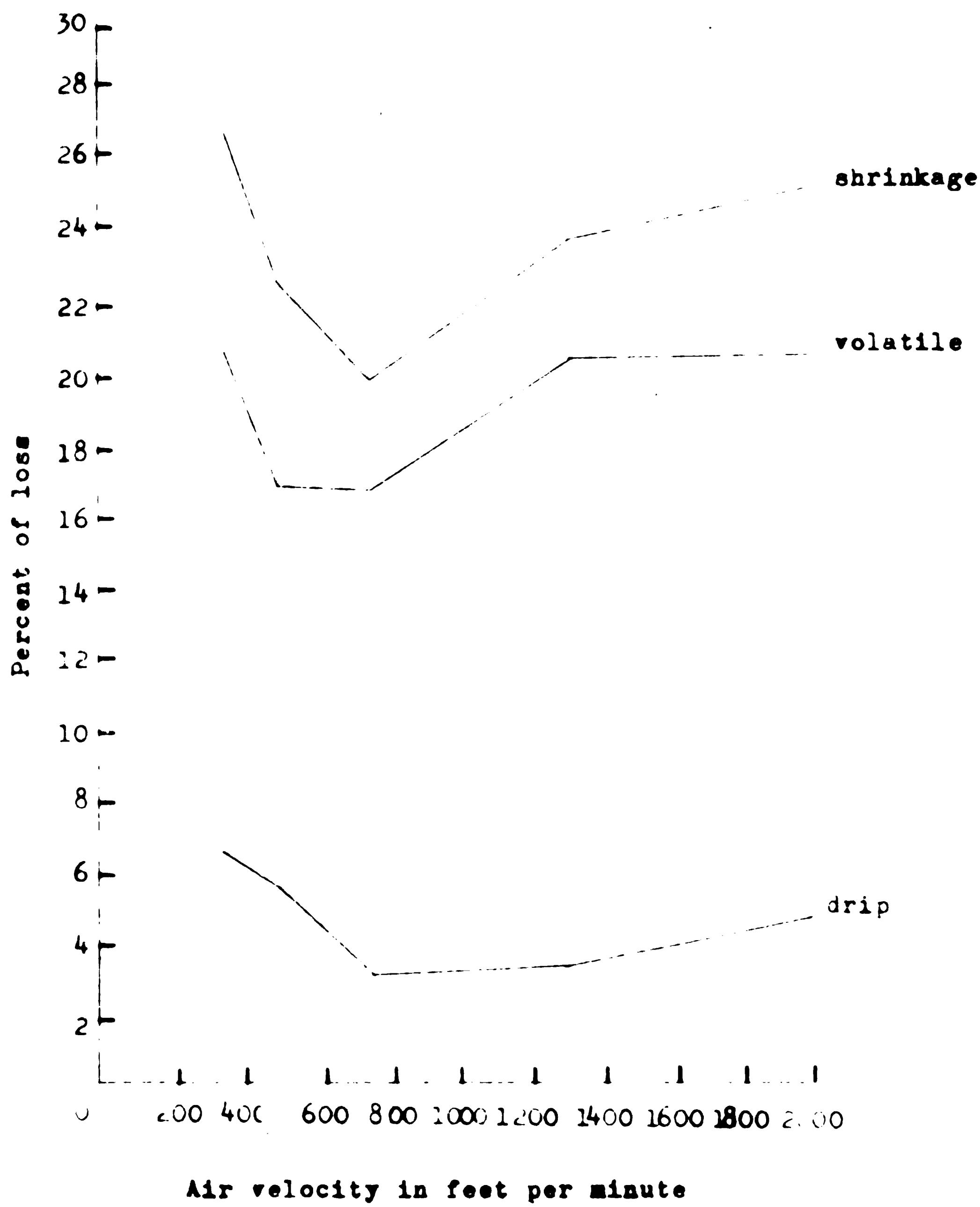


Figure 12. Average fuel consumption at various air velocities and at a cooking temperature of 275 degrees Fahrenheit

DISCUSSION OF RESULTS

The results reported herein indicate that forced convection in roasting ovens can influence the weight shrinkage, fuel consumption and cooking time when roasting beef. Forced convection cooking consists of the movement of air being mechanically moved across and around the surface of the roast. Various air velocities were obtained by utilizing a belt attached to step-pulleys which were driven by an external motor.

These velocities ranged from 350 feet per minute to 2000 feet per minute. An optimum air velocity, at a constant temperature of 275 degrees Fahrenheit, was observed in the area of 769 feet per minute. Information bearing out this statement consisted of evaluating the collected data on the points of the lowest fuel consumption, the least amount of shrinkage and the last area where cooking time was substantially reduced.

When the results achieved at this air velocity of 769 feet per minute and at an oven temperature of 275 degrees Fahrenheit are compared with the results obtained in a normal, conventional, natural convection oven at 350 degrees Fahrenheit, it was found that there was on the average:

a) a decrease in cooking time of 2.48 minutes per pound,
b) a decrease in volatile loss of 2.08 per cent,
c) a decrease in drip loss of 3.15 percent,
d) a decrease in shrinkage of 5.23 percent, and
e) an increase in fuel consumption of 0.17 kilowatt-hours.

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