Sec 2, Ref. 8
Sec. 4, Ref. 1
Sec. 9, Ref. 3

AP-42 Section 9.13.3
Reference 3
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Reference

CHARACTERIZATION OF INDUSTRIAL DEEP FAT FRYER AIR EMISSIONS

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I. SUMMARY

Cooking of snack foods causes emissions of oil to be released as high moisture food products are processed in high temperature vegetable oil cookers. Tests by EPA have shown that vegetable oil is not volatile in virgin form at vegetable oil cooker operating temperatures. However, data have not previously been available to assess the volatility of organic droplets and aerosols, and the possible gaseous organics that are released into the atmosphere from frying processes.

This document summarizes results of particulate and organic matter emission tests performed by Frito-Lay to characterize fryer emissions. The results show that organic emissions from fryers are primarily particulate matter that is not volatile at stack temperatures. Typical total particulate matter emission rates range from 0.2 to about 3 lb/hr. The fraction of the total Method 5 particulate catch that is volatile at 212°F is small, typically in the range of 0.01 to 0.03 lb/hr. Emissions of organic matter that are in the gas phase at ambient temperature and that would not be collected in a Method 5 train are typically low and variable, averaging about 0.1 lb/hr and ranging from 0.03 to 0.3 lb per hour. Limited GC analysis indicates that the methane contributes less than 0.01 lb/hr to the gaseous organic total.

II. PROCESS DESCRIPTION

Industrial deep fat frying is the process by which vegetable and other raw materials are cooked for packaging and later use by consumers. The process involves immersion of the raw material in a hot oil cooker. In the process, the raw food material is cooked, and moisture contained in the food material is driven off and replaced by oil.

Although individual processes differ from one installation to another, the basic process involves raw material preparation, cooking in heated oil, and seasoning, followed by packaging. Although frying processes may be either batch or continuous, all of the processes tested by Frito-Lay for this study are continuous. In continuous processes, food stuff is transported through the cooker either on conveyors or with the circulating oil.

Frito-Lay produces a variety of snack foods using deep fat frying processes at 40 locations in 23 states. The principle products are corn chips, tortilla corn chips, multigrain chips, and potato chips. These products may be produced using one or more of the following vegetable oils -- soybean, canola, sunflower, cottonseed, corn, and peanut. Peanut and corn oil are currently in only limited use at Frito-Lay installations. A pork rind product, cooked in animal fat, is also produced by Frito-Lay. This product was not tested for this study.

The cookers tested by Frito-Lay range in capacity from 950 to 5000 lb per hour of finished product. Most Frito-Lay cookers, for all products except potato chips, are a proprietary, unique horseshoe shaped configuration designed and built by Frito-Lay. Both direct and indirect fired cookers are used by Frito-Lay. In the case of direct firing, the combustion process and combustion gases are isolated from the cooker oil and cooker exhaust.

III. EMISSIONS

Particulate matter is the major pollutant emitted from deep fat frying. Typical particulate emission rates are in the range of 0.2 to about 3 lb/hr. Emissions result from the violent, turbulent action that occurs when raw foodstuffs with moisture are introduced into the hot oil. The steam release causes entrainment and spatter of cooking oil droplets which are carried away in the high moisture exhaust stream. All continuous Frito-Lay cookers are equipped with hoods which completely enclose the cooker surface, with the exception of the in-feed and take-out openings. The hoods are exhausted outside of the building. The hot steam creates sufficient induced draft to contain and convey steam and oil emissions up the stack. In certain cases, exhaust fans are needed with add-on particulate control equipment. The induced draft also causes a variable amount of room air to be drawn in the in-feed and take-out openings. Frito-Lay exhaust stacks are generally equipped with dampers which are adjusted to limit exhaust flow to levels that are consistent with process quality needs and that ensure complete capture of emissions.

Particulate Matter Emissions

Particulate matter emission rates are believed to vary as a function of process throughput, oil temperature, moisture content of the feed material, equipment design and configuration, and stack emission controls. High moisture raw foodstuff such as potatoes, and high temperature processes generally produce the highest emission rates.

Industrial deep fat fryer particulate emissions are subject to State and local emission limits which vary from jurisdiction to jurisdiction. State and local authorities typically determine deep fat fryer particulate emissions using the total EPA Method 5 front half and back half catch.

Particulate matter emission control equipment is employed on fryer exhaust streams at some Frito-Lay installations where uncontrolled emissions are relatively high and/or where required by local regulation. The exhaust streams contain oil and large quantities of water vapor. Mist eliminators and impingement devices are effective in removing large oil droplets, and in scrubbing and collecting the mixture of condensed water and organics in the stream. Electrostatic precipitators (ESPs) and wet scrubbers are used at some installations. Where ESPs are used, condensed water vapor must be prevented from causing arcing of the ESP electrodes. In one series of tests performed by Frito-Lay, a condenser/ESP system was in place, but the electrodes were not energized. The results showed that much of the removal of particulate matter (Method 5 front half and back half) can occur from scrubbing, impingement, and settling of large oil droplets.

Catalytic and thermal incinerators are not used at Frito-Lay facilities. Due to the presence of water and oil droplets, catalytic incineration has not been a viable technology. Thermal incinerators would be very costly to operate due to high moisture, low organic content fryer exhaust streams, and would have a very poor cost effectiveness due to the small amount of material removed.

Frito-Lay particulate matter emission compliance test results from processes that represent a cross section of the product processes operated by Frito-Lay are shown in **Table 1**. These data cover a range of products, oils, and processes conditions.

Particulate Matter Emission Factors

Based on the data presented in Table 1, emission factors calculated for Frito-Lay processes are the following:

Corn chips inlet to ESP – 0.56 lb PM/ton finished product
Corn chips after oil mist eliminator -- 0.51 lb PM/ton finished product
Potato chips inlet to scrubber – 1.6 lb PM/ton finished product
Corn tortilla chips uncontrolled – 0.33 lb PM/ton finished product
Multigrain chips uncontrolled -- 0.83 lb PM/ton finished product

Volatile Organic Emissions – Due to the very low vapor pressure of soybean and other vegetable oils, it has generally been assumed that emissions from deep fat fryers are not a significant VOC source. A recent study by EPA has confirmed that soybean oil will not boil at atmospheric pressure. When an oil sample is subjected to an increasing heat rate, the oil eventually chars, thermally cracking the fatty acid triglycerides to release hydrocarbons and aldehydes. On the basis of this study, EPA has concluded that soybean and other vegetable oils should not be subject to VOC regulations. However, the EPA study left open the question of whether deep fat cooking processes should be exempt from consideration as a VOC, because splatter and entrainment of vegetable oil in the high moisture exhaust stream may crack or oxidize vegetable oil to form lower molecular weight, higher volatility compounds.

To answer this question, Frito-Lay has evaluated previous organic emission data, and has conducted additional field studies to determine VOC emission rates from product-processes that are typical of the company's operations. The studies and analysis by Frito-Lay were designed to address two issues raised by EPA:

(1) What is the emission rate of gaseous organic compounds, and

(2) What is the volatility of particulate matter collected in the front half and the back half of the EPA Method 5 sampling train?

1. Gaseous Organic Emissions. Studies to assess gaseous organic emission rates were performed at four sites on a total of 7 different fryers and 6 different products. The tested product-processes are typical of Frito-Lay processes and products, and include high temperature and high feed moisture conditions expected to produce the highest emissions.

Characterization of fryer exhaust streams is difficult due to the high moisture loading and liquid oil droplets. At the fryer hood exit, exhaust stream temperatures can approach 285°F. The exhaust gases are cooled in the exhaust duct and stack due to heat loss through the duct walls and, in some cases, by water-cooled condensers or scrubbers. Condensed water and oil droplets fall out and are scrubbed from the stream, even when no control equipment is installed or operating. Accurate characterization of the small gaseous organic component of fryer exhaust is challenging.

Several different measurement methods were used by Frito-Lay. These included EPA Method 25 (on-site Byron Analysis), EPA Method 25A (on-site FID Analysis), and EPA Method 18 (GC/FID). Due to the very high moisture content of streams, and presence of liquid droplets, stack samples were drawn through condensate traps and filters prior to injection into the analyzers. The condensate trap temperatures

differed from test to test. Also, in several tests, the sample streams were drawn from the outlet of the back half of Method 5 trains, upstream of the silica gel impinger. The products/processes that were tested, process data, test conditions and test results are presented in **Table 2.**

The data indicate that rates of total organic emissions that are in the gas phase at ambient temperatures are very low. Samples, taken from the stack and analyzed at the outlet of Method 5 and at the outlet of similar impingers, show total organic mass rates (as methane) ranging from 0.03 to 0.18 lb/hr for all tested products/processes except in the case of a new product that was tested during production start-up. Organic emissions of 0.09 to 0.35 lb./hr were found for that process.

The GC/FID data on a sample collected at the outlet of Method 5 showed the gaseous organic compounds to be C5 or lower hydrocarbons. The total emission rates of non-methane organic hydrocarbons was indicated to be 0.006 to 0.043 lb/hr. In 3 of the 4 GC/FID samples, the methane concentration was low, ranging from 2.1 to 5.8 ppm (0.007 - 0.009 lb/hr). The remaining GC/FID methane result was much higher -- 30.9 ppm (~ 0.1 lb/hr). Although there is no explanation, the validity of this result is doubtful.

Samples taken from the stack and analyzed at the outlet of higher temperature condensate trap (~ 120°F) indicate total HC emission rates ranging from 0.26 to 0.37 lb/hr. These data include condensible matter that is measured as particulate matter in the Method 5 "back half."

2. Particulate Volatility Assessment. Studies to assess the volatility of particulate matter emissions were performed using Thermogravametric Analysis (TGA). This is a standard laboratory procedure that measures the weight loss of a sample subjected to increasingly higher temperatures. This procedure was used to assess the volatility of the Method 5 front half and back half catch, collected at 4 product-processes. The Method 5 front half catch is expected to consist of oil droplets that are caught and retained on the front half filter. The back half catch is not well understood, but may include organic material that migrates through the front half filter over the duration of the Method 5 run, condensible organic matter, or very fine particles that are not caught on the Method 5 filter. EPA Method 24 which is applicable for determining the volatile matter content of surface coatings, is not applicable for determining the volatility of the Method 5 front half or back half catch from vegetable fryer emissions, due to the inability to collect sufficient sample for Method 24 analysis. Similarly, samples collected in a condensate trap are not amenable to analysis with Method 24 due to the inability to separate the water/oil emulsion.

Method 5 samples were collected for TGA analysis at the following products/processes:

- Multigrain chips/canola Oil
- Potato chips/ cottonseed oil
- Corn chips/sunflower oil
- Tortilla corn chips/soybean Oil

The TGA results are shown in **Figures 1 - 4.** These results show that the volatility of all samples is low at stack gas exhaust temperatures. For the front half catch, the TGA results show essentially no (2% or less) weight loss at 212°F. For 3 of the 4 products/processes (potato chips, corn chips, and tortilla corn chips,) the back half weight loss at 212°F ranged from 8% to 20%. Particulate matter data are not available for these three tests. The multigrain chip results indicated 34% back half weight loss at 212°F. The back half particulate matter result for that test is 0.08 lb/hr.

Based on the back half particulate matter shown in table 2 and the TGA results, calculated back half, volatile particulate matter emission rates are as follows:

- Multigrain chips 0.03 lb/hr (0.1 tpy)
- Tortilla corn chips 0.01 lb/hr (0.05 tpy)
- Potato chips 0.08 lb/hr (0.35 tpy)
- Corn chips 0.03 lb/hr (0.12 tpy)

IV. CONCLUSIONS

The test data collected by Frito-Lay support the conclusion that emissions from vegetable oil fryers are primarily composed of non-volatile particulate matter. Total particulate matter emission rates measured with the front half and back half of Method 5 range from 0.2 to about 3 lb./hr. The Method 5 back half catch, while relatively low in absolute terms, contributes significantly to the total Method 5 catch for some product/processes, and it is reasonable to include the back half in the particulate total. Tests performed with TGA analysis show that the front half catch is not volatile at 212°F. TGA tests of the back half catch indicate a small, but essentially negligible quantity of volatile matter in the range of 0.01 to 0.03 lb/hr.

Gaseous organic emission rates measured at ambient temperatures, although variable, are shown to be low, in the range of 0.03 to 0.2 lbs./hr., except for the new process line which indicated rates up to 0.35 lb./hr. during startup tests. Higher gaseous organic emission rates, in the range of 0.3 to 0.5 lb/hr were measured at higher sampling temperatures. A major portion of these emissions would be particulate matter that would be collected in the front or back half of a Method 5 train, and based on the TGA analysis, would have low volatility.

Table 1
Particulate Matter Emissions

Oil and Product	Cooker Design	Operating rate, lb/hr	Cooker Temp, deg F.	Stack Temp deg. F.	Sample Location	Particulate Matter (lb./hr.)	Back Half Particulate Matter (lb./hr.)
Sunflower Oil, Corn chips (High temp. process, with condenser, ESP controls)	Two fryers, each 950 lb./hr. "U" fryers, pan heat	2139	410	240	Inlet	0.6	0.3
		1846		187	ESP Outlet, Cond. off	0.32	0.21
		2062		147	ESP outlet, ESP off	0.24	0.11
Cottonseed Oil, Potato chips (High moisture process, scrubber control)	5000 lb./hr. Steam heat	4039	360	221	Inlet	3.34	0.78
Sunflower Oil Corn chips (High temperature Process)	2200 lb./hr. "U" fryer, steam heat	1970	410	233	Stack	0.5	0.34
Soybean Oil Tortilla corn chips	2200 lb./hr. "U" fryer, steam heat	2089	370	185	Stack	0.35	0.14
Canola Oil Multigrain chip	2600 lb./hr. Surface fry, steam heat	2420	370	208	Stack	0.98	0.26

Table 2
Gaseous VOC Emissions

Oil and Product	Cooker Design	Operating rate, lb/hr	Cooker Temp, deg F.	Stack Temp deg. F.	Trap Temp deg. F.	Sample Location	Total HC (lb./hr.)	Total NMHC (lb./hr.)	Comments
Sunflower Oil, Corn chips (High temp. process, with condenser, ESP controls)	Two fryers, each 950 lb./hr. "U" fryers, pan heat	2139	410	240	~80	Inlet		0.47	-Byron 301 HT GC/FID -1 sample/3 minutes - lb./hr. as Methane
		1846		187		ESP Outlet, Cond. off		0.54	
		2062		147		ESP outlet, ESP off		0.32	
Cottonseed Oil, Potato chips (High moisture process, scrubber control)	5000 lb./hr. Steam heat	4039	360	221	~60	Inlet	0.03		-OVA FID - lb/hr as methane
					~120	Inlet	0.26		- Bechman Fid - lb/hr as methane
					~60	Inlet, M-5 outlet		0.04	C2 - C6 HC -GC/FID as methane
Sunflower Oil Corn chips (High temperature Process)	2200 lb./hr. "U" fryer, steam heat	1970	410	240	~60	Stack	0.05		-OVA FID - lb/hr as methane
					~120	Stack	0.37		- Bechman FID - lb/hr as methane
					~60	Stack, M-5 outlet		0.02	C2 - C6 HC -GC/FID as methane
Soybean Oil Tortilla corn chips	2200 lb./hr. "U" fryer, steam heat	2089	370	157	~60	Stack	0.1		-Bendix FID - lb/hr as methane
			370	190	~60	Stack	0.12		
			360	190	~60	Stack	0.18		
						M-5 outlet	0.1		
Canola Oil Multigrain chip	2600 lb./hr. Surface fry, steam heat	2420	370	208	~60	Stack	0.3		
						M-5 outlet	0.17		

FIGURE 1

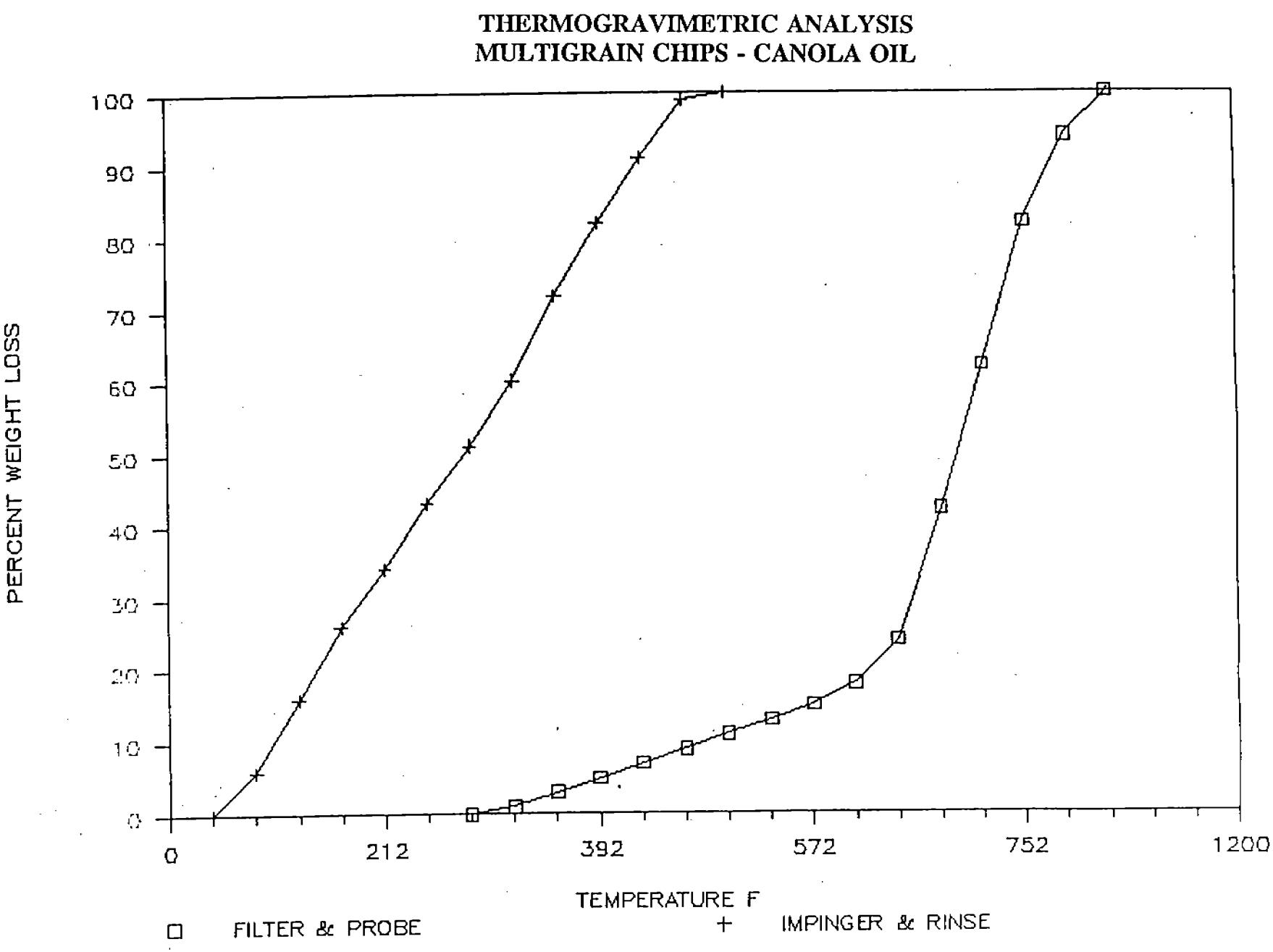
THERMOGRAVIMETRIC ANALYSIS
MULTIGRAIN CHIPS - CANOLA OIL
PERCENT WEIGHT LOSS
100
90
80
70
60
50
40
30
20
10
0
0
212
392
572
752
1200
TEMPERATURE F
FILTER & PROBE
IMPINGER & RINSE

FIGURE 2

THERMOGRAVIMETRIC ANALYSIS
POTATO CHIPS - COTTONSEED OIL

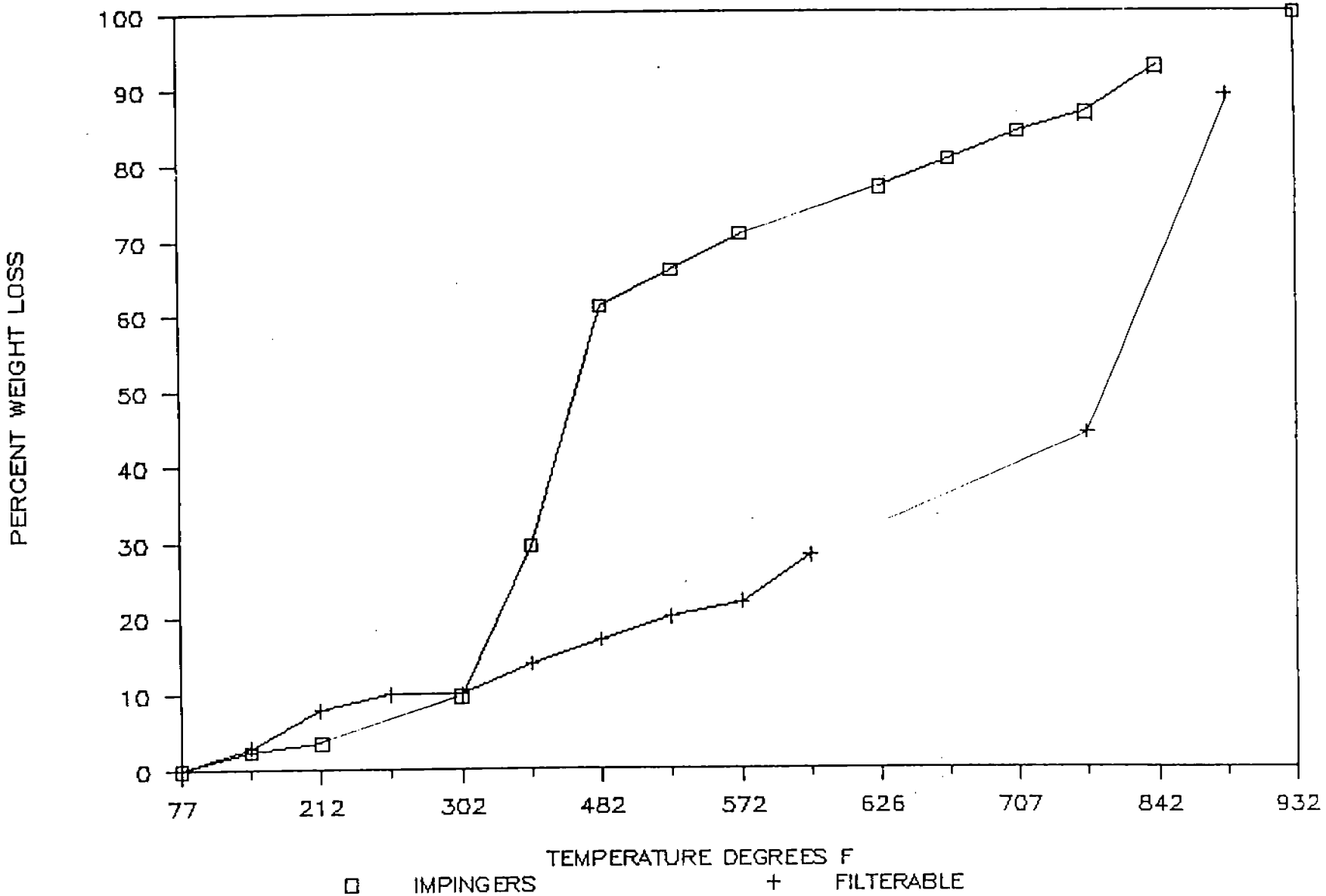

FIGURE 3

THERMOGRAVIMETRIC ANALYSIS
CORN CHIPS - SUNFLOWER OIL

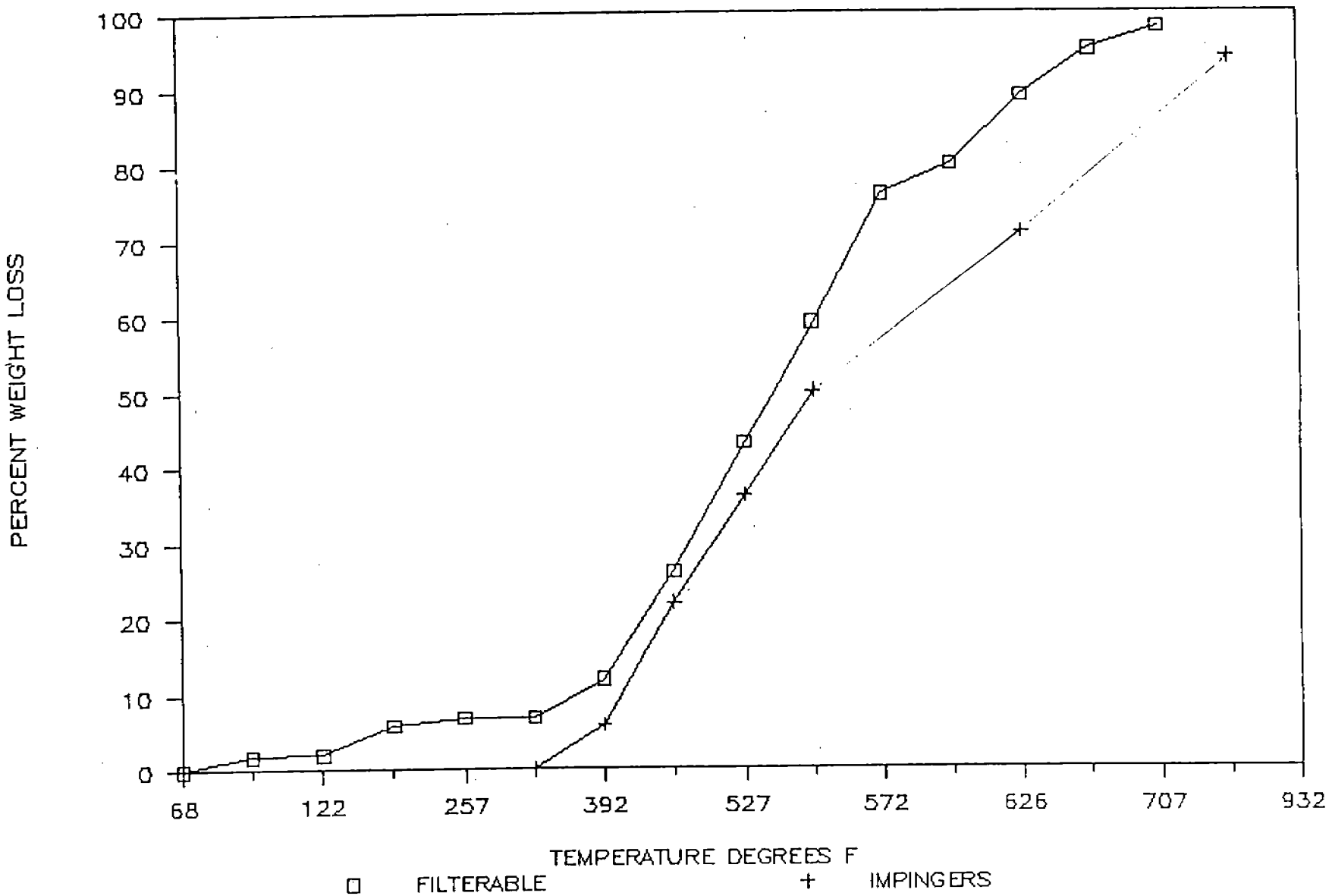

FIGURE 4

THERMOGRAVIMETRIC ANALYSIS
TORTILLA CORN CHIPS - SOYBEAN OIL