Study of Abatement Methods and Meteorological Conditions for Optimum Dispersion of Particulates from Field Burning of Rice Straw

Rice Straw Incinerator Evaluation

ARB Project 1-102-1

University of California

Davis, California

Principal Investigators

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Abstract

The project was initiated in December, 1970, to determine the potentials of mobile incineration as a practical means of reducing particulate emissions from combustive disposal of rice field residues. Previous studies on incinerators indicated improved combustion is possible under controlled conditions. Capacity, mobility, durability, economics, wild fire control and other problems existed. However, information on the state of the art was needed under California rice field conditions because of the continuing need to reduce all contributions to the statewide air pollution problem.

An experimental mobile field sanitizer (incinerator) was transported from Oregon to California. Test runs and modifications were made on the unit for use on rice field residues in California in the fall of 1971 and spring of 1972. Tests were also conducted in barley fields during the spring and summer of 1972 on a mobile straw burner prototype developed by an inventor in California.

Results of the tests of both units indicate that the state of the art is not sufficiently developed for use in rice field residue disposal. Projected overall costs of operation are not within the limits of economic feasibility at this time. Under reasonably good climatic conditions in California, well managed open field burns will have less particulate emissions than the incinerator tested. Under poor climatic conditions, the mobile incinerator cannot be operated in rice fields.

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Acknowledgements

Through cooperative efforts between the Department of Agricultural Engineering at the University of California, Davis; the Department of Agricultural Engineering at the Oregon State University, Corvallis; University of California Agricultural Extension, Rice Growers Research Advisory Board in California and the California Air Resources Board, the Oregon State University Mobile Field Sanitizer was transported to California for field testing and modification under rice field conditions in the fall of 1971 and spring of 1972. Many of the Agricultural Engineering Department staff of the University of California participated in the modification and testing of the OSU unit in California. We are deeply indebted to the expertise and untiring efforts of Mr. Russ Bonlie and Mr. Robert Ash of the OSU research team. We also appreciate the efforts of Mr. Jack Davis, Department Chairman of the Agricultural Engineering Department, Oregon State University and Dale Kirk, Project Leader of the OSU Mobile Field Sanitizer project for their part in aiding the project work.

Mr. Ben Thompson, of Live Oak, California, is the inventor and builder of the BEMCO Cyclone Straw Burner. We express our appreciation for his efforts in making his operating model and full scale units available for tests at various stages of development.

We acknowledge with thanks the help and encouragement of Mr. Roy Osterli, Mr. Jack Schiedel and other members of their rice growing operations for their help in providing a place for us to run the tests. Others who played important roles in getting this project work done were as follows:

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Needless to say, there are many more who gave of themselves and their time including radio and TV coverage of the tests. To all we may have missed, we express our sincere thanks for your help.

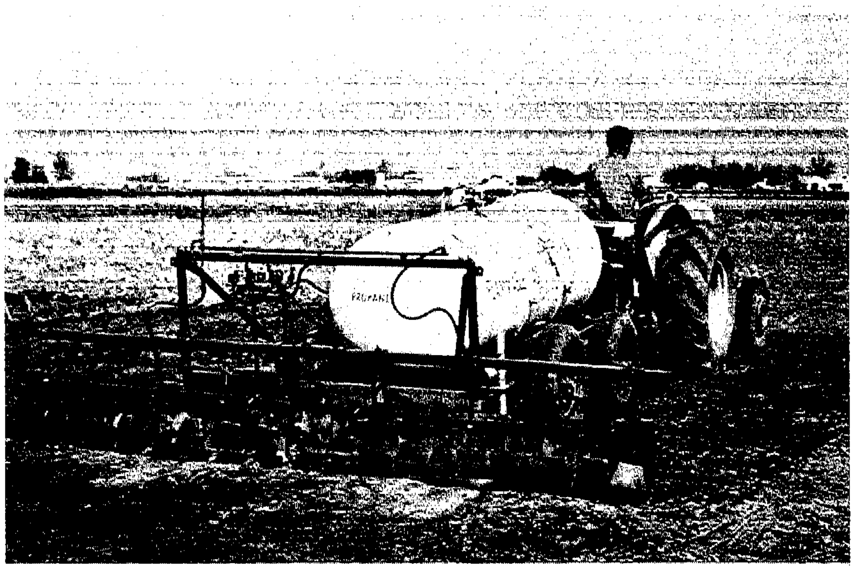

Figure 1. Propane Flamer

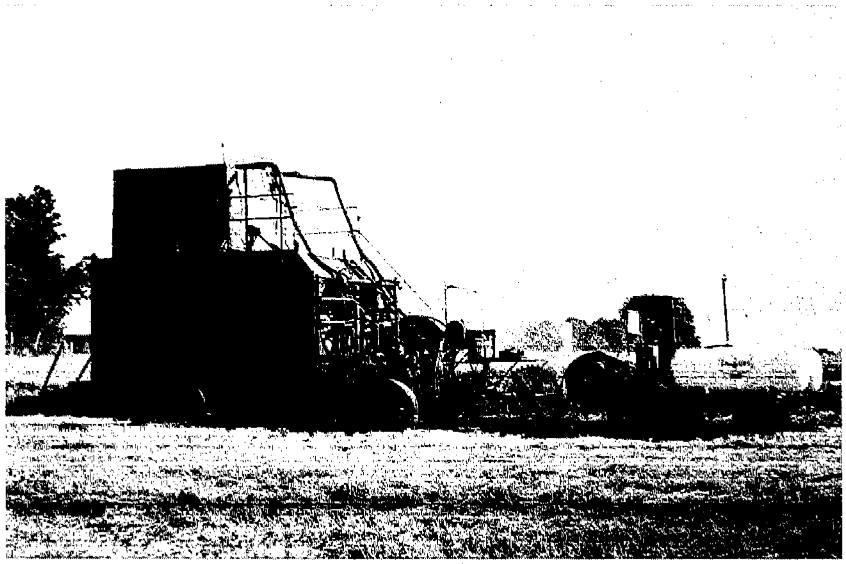

Figure 2. OSU Field Sanitizer

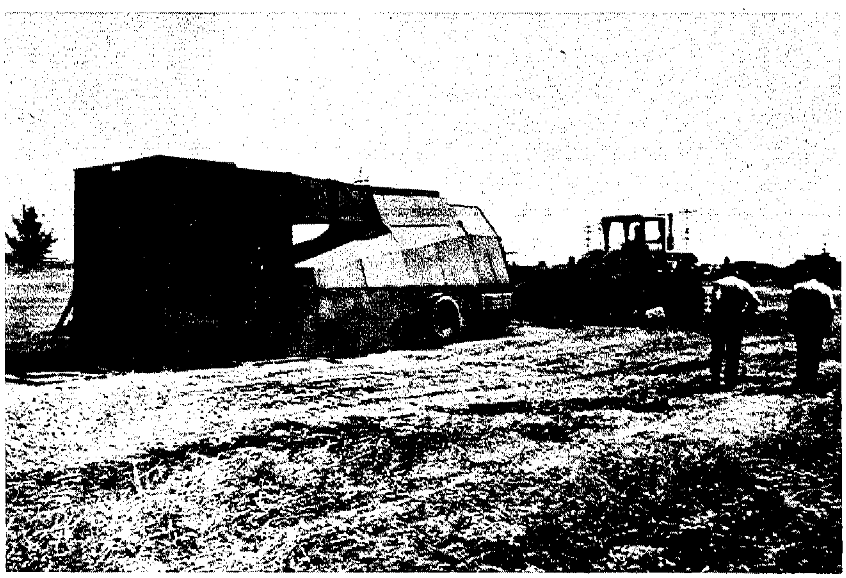

Figure 3. BEMCO Cyclone Burner

Conclusions

The use of field incinerators in rice fields in California does not seem to be practical at their present stage of development. Both units tested have a number of unresolved problems as follows:

1. The estimated investment cost ($15,000 to $25,000 per unit) and low capacity produces high machine and operating costs, estimated to be $37.00 per hectare ($15.00 per acre) or more per year. Open field burning costs are from five cents to two dollars per acre depending on the fuel and fire management system utilized. Current costs are mostly from ten cents to twenty-five cents per acre.[1]
2. Serious problems occurred with wildfires in the field during the field operation of the incinerators. Two to three fire fighting units were required to control wildfires in some cases.
3. The incinerators have poor flotation which only allows them to operate on fairly dry soil. This means that the removal of the residue must be delayed until the soil is sufficiently dry and firm enough to support the machine. (Open field burning can be accomplished on relatively wet soils. In the fall, this permits burning as soon as the straw is dry enough regardless of soil conditions. In both the fall and spring this permits entry of agricultural implements at the earliest possible date for tillage and seed-bed preparation as it removes the straw cover and speeds the drying of the soil.)
4. Difficulty was experienced in maneuvering incinerators in rice and barley fields. This was largely due to weight and size factors and the type of steering and support systems provided.
5. The durability of the firebox materials has been unsatisfactory on those units given extended tests. New materials or methods of protecting firebox liners will be required for practical operation.
6. Units could not burn weeds and escaped rice plants on checks or levees to obtain the same sanitizing possible with open field burning.
7. High particulate emission levels will still be a problem unless some provisions can be made to remove particulates at the incinerator discharge.
8. In some years, there is a lack of available operating time when disposal could be accomplished without a prohibitive number of units

Conclusions
continued ....

required to get the job done. Assuming 122,000 hectares (300,000 acres) burned* , .4 hectares per hour (one acre per hour) capacity, 20 hours per day operating time and 30 days possible for use, 500 units at $15,000 - $25,000 per unit would be required in California. If only 15 days were available, one thousand units would be required. In the 1972-73 burning season, there might have been five days, which would require three thousand units. It is highly possible that many fields would have had <u>no days</u> when an incinerator could have operated in the field during the 1972 fall and 1973 spring burning periods. The costs per acre under these conditions would be ridiculously high. No effort has been made to determine the probability of full utilization, but historical climatic studies are underway that may be able to give a means of evaluating this factor if a suitable incinerator is produced. Under wet field conditions, in years such as 1972-73, open field burning is the only practical combustive means of disposal known at this time.

Some advantages that incinerators appear to offer if other problems can be resolved (disregarding economic aspects) are:

1. The OSU incinerator reduced carbon monoxide and hydrocarbon emissions. The BEMCO Straw Burner has not been completed and put in the field for emission tests as yet.
2. They appear to have potentials for burning higher moisture rice residues 20 - 30% (wet basis) in straw rows if and when soil conditions will permit. However, with reasonable weather conditions, spreading the straw at harvest or raking the windrows can normally reduce the moisture content from this level to 10-12% (wet basis) in 24 hours. At this moisture level, the sanitizer offers no advantage in particulate emissions. Neither of the above operations would approach the cost of incineration as projected at this time.

Prototype tests in Oregon are expected in the summer of 1973 by two Oregon manufacturing concerns as follows:

(a) Turbo Cycle: Eugene, Oregon
(b) Rear Manufacturing Company; Eugene, Oregon

*Appendix F

Conclusions
continued ....

Also, two smaller versions of the OSU machine are being tested at Oregon State University this summer. Liaison has been established with them and if satisfactory operation is indicated, additional information will be obtained. Visits to the test sites may be arranged if appropriate.* Further tests should be made when appreciable changes in these prototype units are made or if commercial production units become available for testing. Until substantial developments occur no further field testing is contemplated.

* Subsequent to this writing, a brief visit was made to Oregon in August to view two units in operational tests (see page 25).

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Recommendations

The results of this project indicate that the present state of the art of mobile field incineration is not sufficiently advanced to be a practical solution to the disposal of the rice crop residues in California. Further, with the many outstanding problems still unsolved, it appears that solutions will not be readily obtained. Even if some of the limiting factors such as: high particulate emissions, durability, maneuverability and fire control were resolved, there still would be the problem of operation in wet soil conditions typical to rice production and the high costs associated with operation and maintenance of this type of unit.

At this time, a unit of this type is not recommended as a means of solving the problem of rice residue management and disposal.

Introduction

Preliminary studies on incinerators at UCD and more extensive research at Oregon State University (OSU), Corvallis, indicated that improved combustion conditions could be produced by controlling temperatures, fuel rates and air supply in burning crop residues. Two trips were made to OSU to become familiar with the research unit being developed under special grant funds from the Oregon State Legislature beginning in 1969 extending through December, 1972.

To obtain preliminary information on the potential benefits of field sanitizing in disease, weed and pest control, simulation tests were conducted in Butte and Sutter county rice fields in the spring of 1971 utilizing a propane field flamer (figure 1) operating at a very slow speed, less than 1.6 km/hr (1 mph), applying approximately the same heat energy to the soil surface as would be provided by the heat from burning rice straw residue in the mobile field sanitizer or other field incinerator burning on the soil surface. Weed specialists, entomology specialists and plant pathologists and county farm advisors participated in the tests. Results indicated that the level of reduction of problems in each area was insufficient to obtain significant benefits except in the control of stem rot disease.[11-19] This disease is also satisfactorily controlled by open field burning of spread straw.

Tests were scheduled and completed in the fall of 1971 and spring of 1972 on the OSU Mobile Field Sanitizer. Tests were also conducted on the BEMCO Straw Burner in the fall of 1971, and spring and summer of 1972. No field tests were conducted in the fall of 1972 or spring of 1973. This was due to field conditions that would not permit operation of either unit plus the fact that no further feasible solutions to the outstanding problems could be discovered by the participants in the project, although considerable thought and study was devoted to this end.

Design, Construction, Materials and Methods

In the fall of 1971, field tests in California rice fields were conducted with the "mobile field sanitizer" developed at Oregon State University. The machine was basically a 10' wide, 20' long, 15' high box supported by six metal wheels.[2,3,4] The burning chamber was ventilated and cooled by forced air and a propane pilot burner was used for primary ignition of the straw. (See Figures 2, 4, 5.) It became apparent that several modifications were necessary for operation of the sanitizer in a rice check. The rotary mowers were designed to cut a clear path in front of the side ground seals to aid in preventing fire spread. They were found to be inadequate in the heavy and tough rice stubble and were removed. The wheel rakes were removed when windrowed straw was burned instead of spread straw. The high pressure air ducts, used for primary combustion and lifting residues up into the firebox, had to be raised because of the tall stubble. These modifications allowed the machine to be run under fall rice field conditions.

During the fall trials, it was apparent that the accordion type ground seals were deteriorating and could not flex enough to seal adequately in the relatively uneven rice field, increasing the problem of wildfires. The stainless steel interior surfaces of the fire box were showing some buckling. Pop rivet fastenings were breaking loose in some areas. With the rainy weather and poor field conditions developing it was necessary to discontinue field operations. Modifications and repairs were planned to conduct further tests when field conditions became satisfactory.

During the fall trials the fixed stainless steel screen gate frequently became fouled with molten straw ash. This severely reduced the air flow and the capacity of the machine. Early in March of 1972 the fixed stainless steel grate was removed and a few runs were made without any screen grate. Substantial quantities of partially burned straw were visible in the discharge from the stack. No data was recorded; however, pictures were taken showing this operating condition. Additionally, some spot ignition of wildfires occured from flaming embers discharged from the stack. The deteriorated ground seals

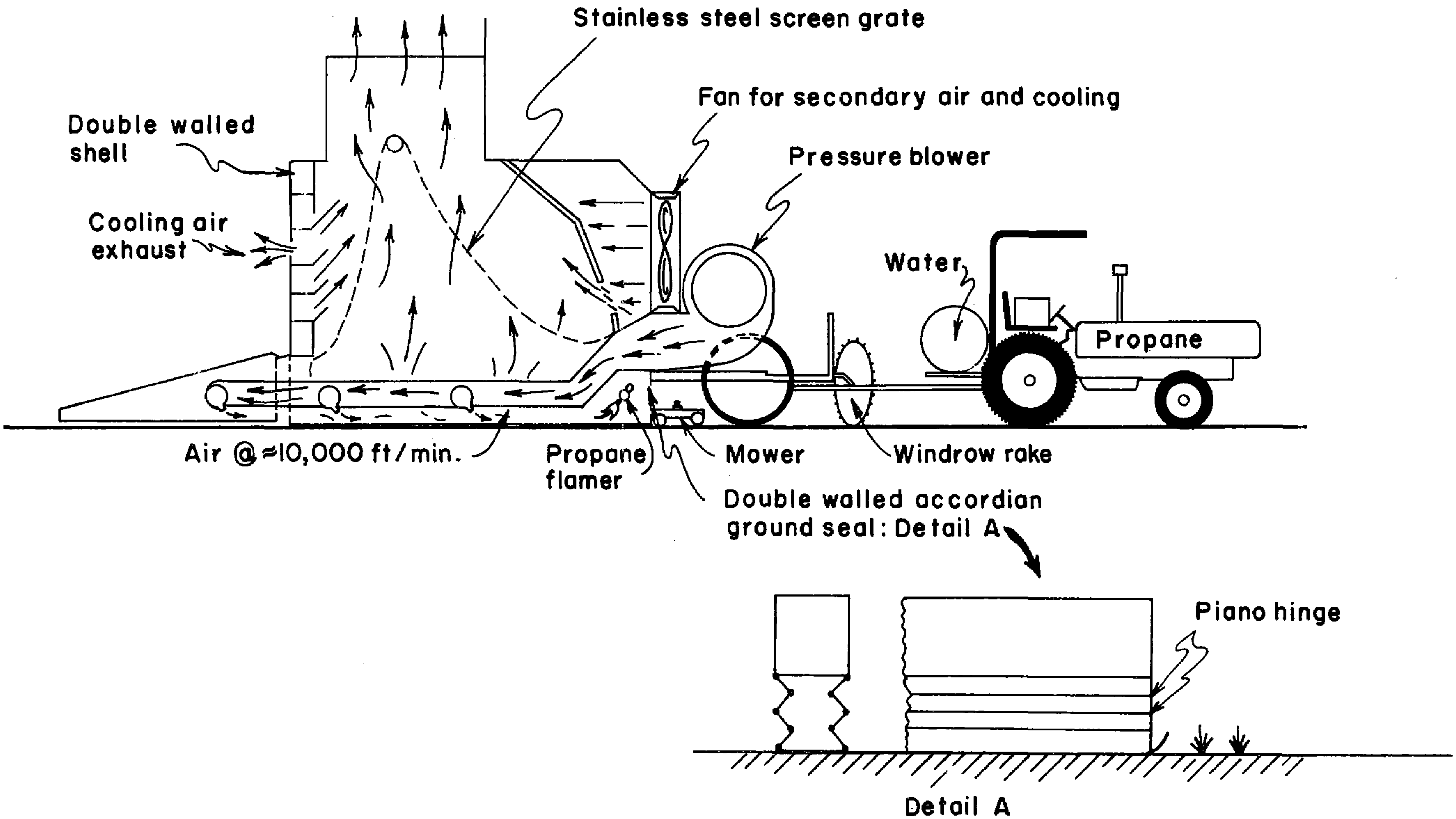


Fig. 4 O.S.U. BURNER BEFORE MODIFICATION

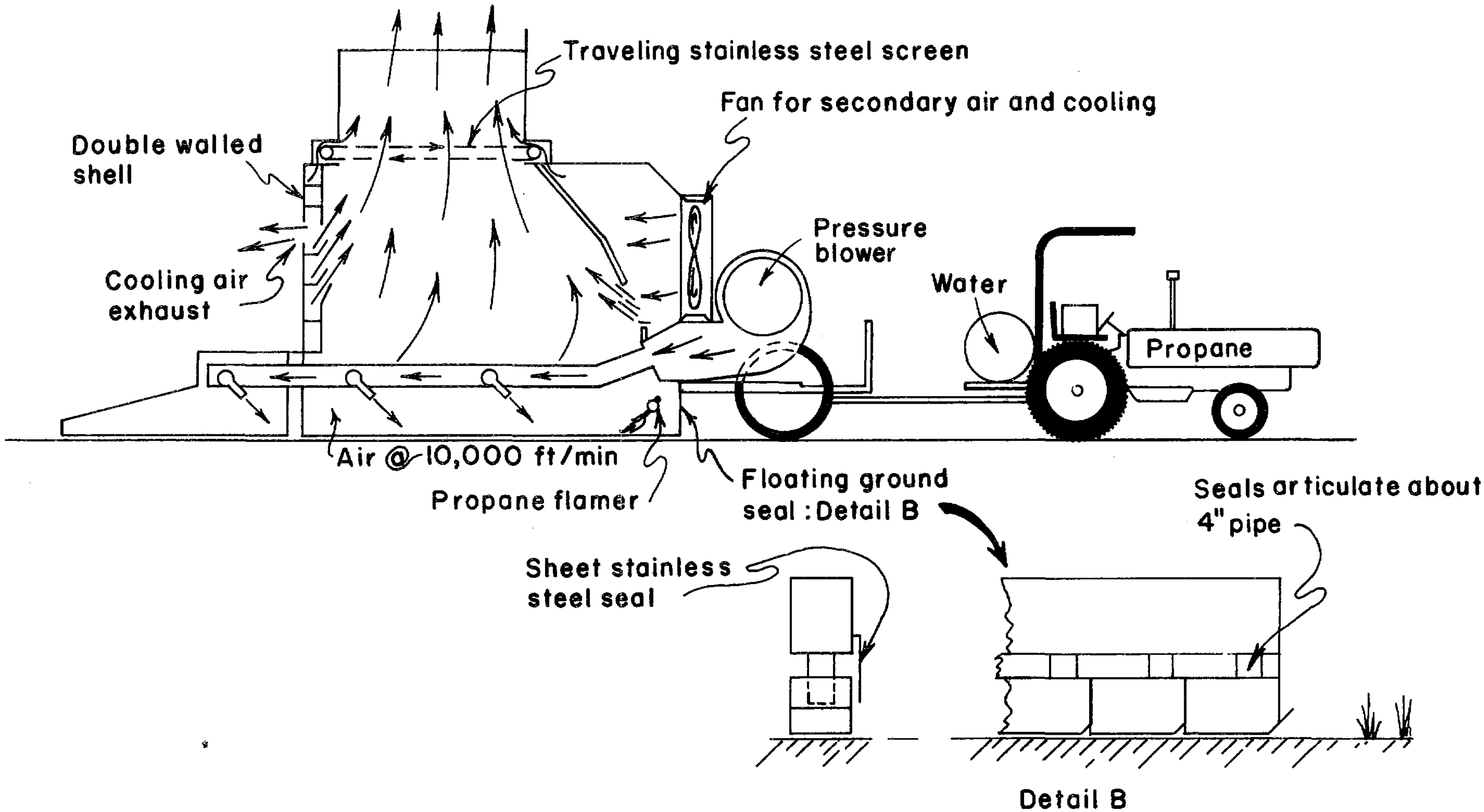


Fig 5

O.S.U. BURNER WITH MODIFICATION MADE IN CALIFORNIA TRIALS were creating even more problems of wildfires from ignition produced on the sides of the incinerator. These fires and those developing at the rear of the unit required the use of two and sometimes three fire fighting units to keep wildfires under control.

Prior to the spring trials in 1972 a new traveling type stainless steel screen grate was planned and constructed in California. The purpose of the traveling screen was to trap partially burned particles, exposing them to further combustion and to remove large particles from the effluent gas. The screen traveled around two metal rollers, one each at the fore and aft ends of the stack (Figure 5). The screen was cleaned and cooled by directing cooling air through it near the fore and aft ends of the screen. The traveling screen grate operated satisfactorily without plugging in the spring trials. New ground seals (see Figure 5) were designed during the winter and added to the machine for the spring trials. The new seals were basically a series of heavy steel boxes which articulated about a four-inch pipe. The new ground seals were only moderately successful. They tended to become jammed with mud and straw and did not solve the problem of wildfires at the sides of the mobile sanitizer.

Operational and Evaluation Phase

The OSU sanitizer was evaluated primarily on its ability to merely operate in California rice field conditions. Parameters such as speed, rate of residue consumption, maneuverability, amount of wildfire ignition and down time were observed. Quantitative measurement of emissions was made on about a third of the runs. Gas measurements were made by collecting a bagged sample over a five to ten minute operating period. The bag, heat sealed mylar, was then taken to the OSU instrument trailer where average hydrocarbon, carbon dioxide and carbon monoxide levels were measured. The skin temperature of the firebox was measured by chromel-alumel thermocouples and recorded on a multi-point strip chart recorder mounted on the tractor. Surface level ground temperatures were measured by three chromel-alumel thermocouples and recorded by strip chart recorders located in the instrument trailer. Particulate measurements were made with an Andersen impacting, eight-stage, non-viable particulate sampler. Collection was made by use of a vacuum fan drawing a sample from the stack through two parallel pipes with an opening in the center of each quarter area of the stack. The eight stage impactor was operated using a vacuum pump pulling 1 cfm through the impactor from the discharge of the vacuum fan. The sampling system was designed to approximately provide isokinetic sampling at each sampling point for designed operation. This sampler was only capable of determining particulates and aerodynamic particulate size distribution of particulates greater than $.43\mu$. This may be a serious limitation as field and laboratory studies of smoke from open field burning reveal that approximately 70% of the mass of particulates $<7\mu$ is less than $.43\mu$. (see App. F) The smoke density measurements were made with a Bailey smoke meter installed in a straight mixing manifold pipe connecting the two parallel stack sampling pipes on the way to the vacuum fan used for particulate measurements. This sampling system was designed installed and operated during Oregon trials before the unit was brought to California and on subsequent tests run on Oregon trials in 1972.

Discussion

Observations of the OSU machine indicated that at its current state of development, it had field operating characteristics that made it impractical for use in California rice production. From an economic viewpoint, the field sanitizer did not appear to have sufficient field capacity (.49 ha/hr, 1.2 ac/hr) to offset operating expenses and depreciation of the estimated high initial cost. Based on estimated costs under Oregon conditions, use in rice fields would be $37 per hectare ($15 per acre) or more. This is not considered economically feasible under average potentials of net profit estimated at $62 to $99 per hectare ($25 to $40 per acre) in 1972.[6,7,8,10]

In addition to the high operating and depreciation costs the machine has high maintenance costs. The stainless steel liner of the box lasted for only perhaps 40-50 hours before showing signs of excessive deterioration. Other firebox liner materials are being tested in subsequent tests in Oregon. The results are not complete, and finding an effective, long lasting and mechanically durable liner appears to be a significant problem.

The typically wet soil conditions, both in the fall and spring, led to flotation problems. The heavy machine required fairly dry soil to work on. This is a definite disadvantage of the sanitizer. Burning with the sanitizer must be postponed until the ground dries sufficiently. Open field burning does not require dry ground necessarily; and, in fact, will allow earlier entry into the field by heavy equipment by removing the straw cover and speeding soil drying. The flotation problem may be partially solved by using conventional track-type flotation with an increased cost.

The sanitizer did not reduce particulate emissions (in pounds per ton of rice straw) in the size range $<.43\mu$ - $>7\mu$ compared to open field burning simulations. The OSU burner picked up the residue and burned it in an airborne state, thus much of the residue ash left the machine through the stack causing the high total particulate emission. One major advantage the sanitizer did have over open field burning is that it could burn higher moisture content straw and stubble (20 to 30% wet basis) effectively.[16] The unit also reduces emissions of carbon monoxide and unburned hydrocarbons compared to open field burns.

The machine apparently has good potentials for use in Oregon where crop yields are actually increased by fire sanitation. In Oregon grass seed culture, the fields are not cut up by irrigation levees or checks; the soil is drier during the burning season and better able to support the weight of the sanitizer on wheels. The residue is generally of higher moisture content due to summer rains, high humidity, and perennial grass regrowth and requires a longer period of combustion and the higher controlled temperatures obtained in the field sanitizer. However, at this time it does not appear suited for use in rice production in California.

Table 1 compares Riverside laboratory spread straw open field burn simulations with incinerator data on the basis of pounds of emissions produced per ton of fuel burned. Another appropriate comparison shown is pounds of emissions produced per acre burned. The incinerator burns nearly 100% of the fuel while open field burning consumes about 75% of the fuel. The figures below are based on an average acre of rice residue defined for these studies as 6,000 pounds of fuel per acre, and the above percentages.

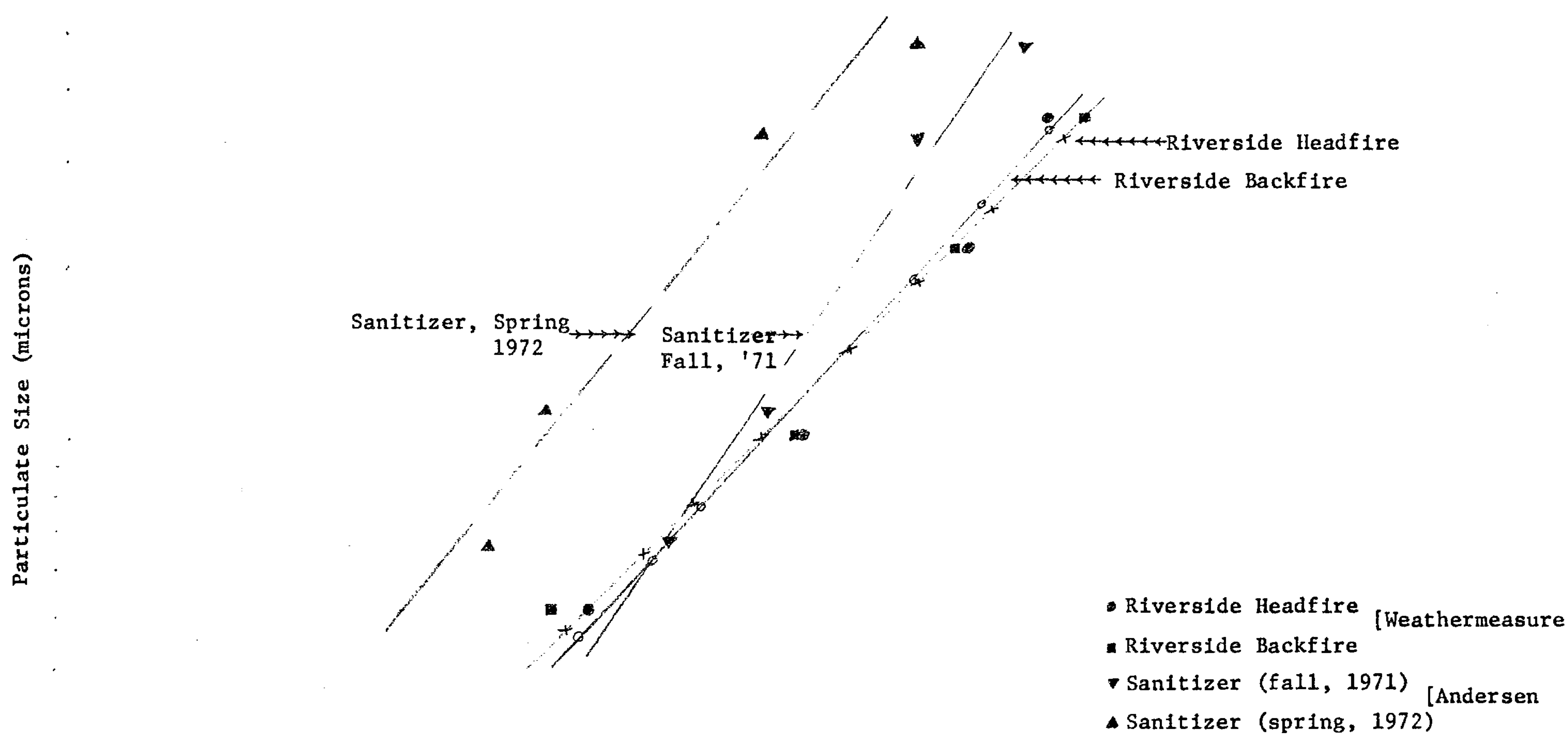
Table 1.
Riverside Lab Simulations of Open Field Burning of Rice Straw vs. Mobile Field Sanitizer

	Particulates*		Hydrocarbons		CO	
Riverside Tower Data[16]	kg/mt	(lb/ton)	kg/mt	(lb/ton)	kg/mt	(lb/ton)
Headfire	1.5	(3.0)	6	(11)	50	(100)
Backfire	.7	(1.3)	4.5	(9)	50	(100)
OSU Sanitizer Data	2.9	(5.7)	.5	(1)	12.5	(25)
Riverside Tower Data	kg/ha	(lb/ac)	kg/ha	(lb/ac)	kg/ha	(lb/ac)
Headfire	8.6	(6.9)	31	(25)	277	(225)
Backfire	3.5	(2.8)	25	(20)	277	(225)
OSU Sanitizer Data	21.4	(17.1)	4	(3)	92	(75)

Straw moisture for all tests was between 10 and 12% (wet basis).

* $>.43\mu - <7\mu$

Aerodynamic Particulate Size
Distribution (>.43μ & <7μ)



*See Appendix F for tabulated data

Fig. 6 Cumulative Percent of Total Particulate Weight >.43 & <7μ

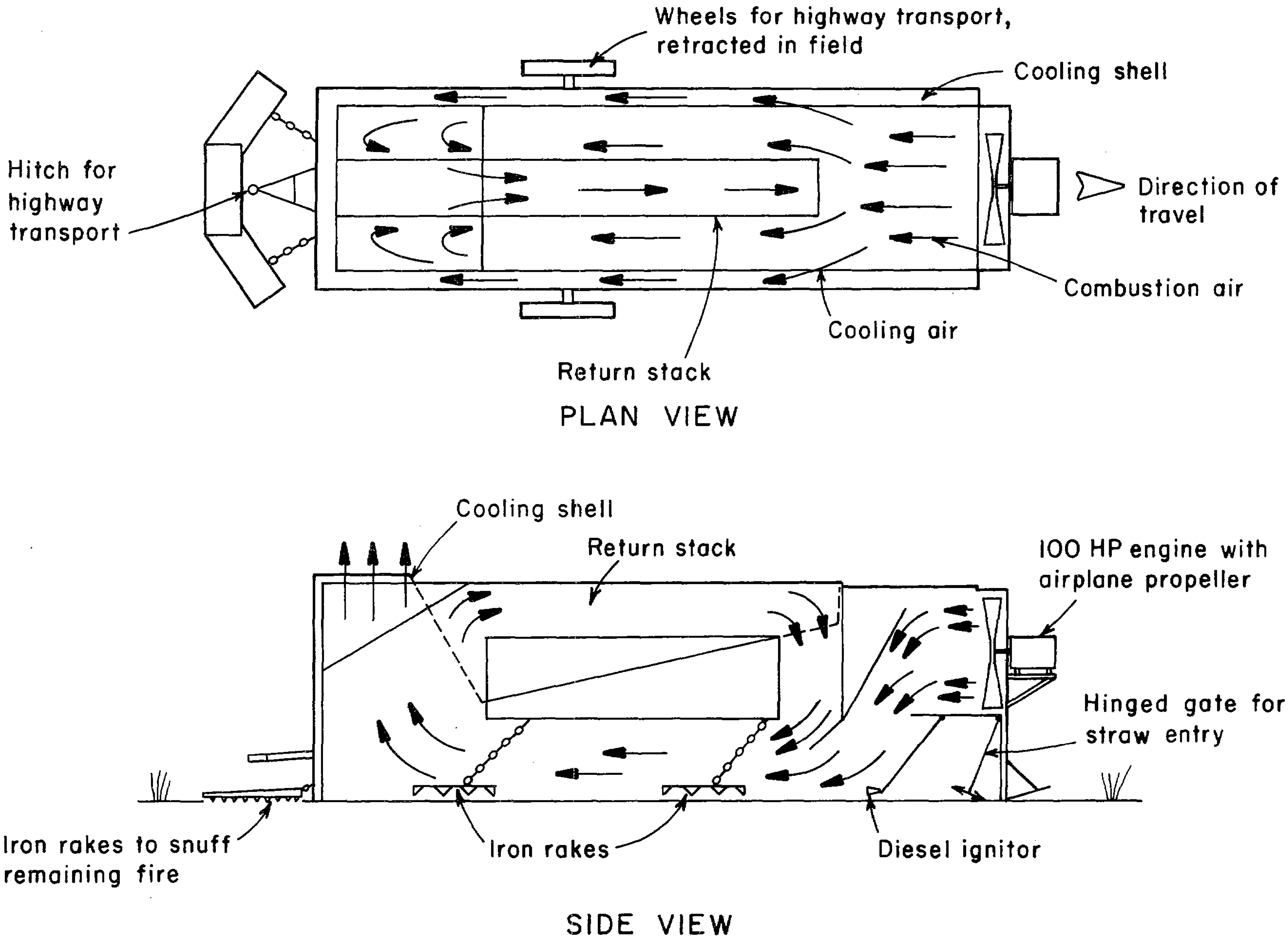


Fig. 7 BEMCO CYCLONE BURNER

Discussion
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Table 2.

Summary for Operational Data
for OSU Sanitizer in Rice Straw

Speed	Approximately 1.6 km/hr (1 mph)
Field Capacity	.49 ha/hr (1.2 ac/hr), 3.3 mt/hr (3.6 ton/hr)
Particulate emissions	
Total >.43μ	75 kg/mt (149 lb/ton) (averages based on seven observations)
>.43μ < 7μ	2.9 kg/mt (5.7 lb/ton) of rice straw, dry wt. (averages based on seven observations)
Firebox temperature	529 - 649 °C (1000-1200°F) measured at firebox skin
Straw Moisture	13% (wet basis)
Stubble Moisture	56% (wet basis)

See appendices A and B for complete field data

In the fall of 1971, some preliminary observations were made on the BEMCO Cyclone Burner developed by Mr. Ben Thompson of Live Oak, California. Further observations were made in the spring and summer of 1972 in barley field burns at the University of California at Davis. This machine differed from the OSU machine in that it endeavored to employ the return stack principle (used in most orchard heaters) in an attempt to reduce emissions. (See Figure 7.) The tests conducted on barley straw and stubble fields had about one-third the quantity of residue of rice fields.

The BEMCO machine was hampered by some of the same problems as the OSU machine. It appeared that improvements in operational procedure, improved initial ignition techniques, and increased fire temperatures could provide for some increase in the speed of the machine. However, it has not been developed to the point where final evaluations can be made of its potential at this time. Progress on modifications is being delayed by a lack of development funds.

Quality of combustion was reduced because of loss of heat in the firebox while turning. Test No. 6 (see Appendix C) indicates when fuel is run continuously into the machine, it will burn hotter and cleaner, perhaps as high as 926 °C (1700 °F).

The BEMCO machine burned material on the ground, and a substantial quantity of ash was left on the ground behind the machine. This may give rise to lower total particulate emissions because less ash is forced to leave the incinerator through the stack.

Table 3.

Summary of Operational Data
for BEMCO Straw Burner in Barley Straw

Speed	approximately 3.4 km/hr (2.1 mph)
Field capacity	2.16 mt/hr (2.3 ton/hr) (7' width at 100% field efficiency) (equivalent of .7 ha/hr [1.8 ac/hr] in a rice field.)
Particulate Emissions	No data; some white smoke was visible at times, indicative of incomplete combustion and small particles.
Firebox temperature	Average: 760°C (1400 °F) Maximum: 926 °C (1700°F)
Straw Moisture	4% wet basis
Stubble Moisture	5% wet basis

Discussions
continued .....

In the spring of 1973, the operation of an above-ground air curtain destructor[9-14] incinerator was observed at the USDA Field Station, University of California, Riverside. The unit operated without visible emissions and had a capacity of about 2.2 mt/hr (2.5 ton/hr). The unit was designed for palm fronds and slash, but the principle may have application in field residues. A major disadvantage is that it operates with a positive pressure in the firebox. The positive pressure would tend to force the fire out of the firebox underneath the ground seals, making fire control difficult. The development of this technique will be followed to determine possible application to field residue disposal. No emission measurements were made on this test. Temperatures were recorded at many points in the firebox and on a movable staff at several intervals over the discharge from the firebox. This data has not been reported as yet.

A brief visit was made to view field tests of one of the small experimental test units at OSU and the Turbo cycle unit near Eugene, Oregon in August 1973. Substantial progress had been made but problems still existed in firebox liner durability, fan mechanical difficulties, fire control and speed of operation [1.6 km/hr (1 mph)], even after the loose straw had been removed from the field. Developers were optimistic about plans to overcome these difficulties but the problems are still substantial. No new cost figures have been developed as yet nor had emission tests been conducted on these units according to the research leaders. From a visibility standpoint emissions appeared to be very light under most continuous operations. It now appears that field sanitizer (mobile incinerator operation) operation in Oregon is going to be used only after the straw residue has first been removed. This reduces the heat dissipation requirements by approximately one-half to two-thirds which should aid in extending firebox durability. Removal of straw from seed crops in the summer months by various methods can be practical in Oregon if a market for the material can be developed. Removal of straw from the rice crop in the fall in California is a more difficult problem considering the wet soils, potential rains, and potentially poorer drying conditions in some years. Flotation of machinery and maneuverability in wet soils and irregular rice check areas remain additional problems of incineration in California rice production.

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GLOSSARY

Backfire	-A line fire with the flame front progressing into the wind
Headfire (front fire)	-A line fire with the flame front progressing with the wind.
Incinerator (burner)	-A unit that burns materials under controlled conditions of fuel supply, air supply and firebox temperature.
Sanitizer	-A unit that utilizes the heat from incineration to sanitize the soil surface, destroying pests and pathogens.
Wildfires	-Uncontrollable fires that develop as a result of operation of a mobile field incinerator. These may be the result of fire leakage at the ground seal, latent smolder spots flaring up behind the unit and fire control system or from embers emitted from the stack which produce ignition in unburned residues.

Fall 1971 and Spring 1972 - OSU Incinerator Trials in Rice Fields

(metric units)

	Field Conditions				Operation Data			(Smoke)		Stack Sampling				(Gas)
		Moisture (%) (wet basis)		Density (dry wt.)	Speed		Rate	Avg. Smoke Density -		Hydrocarbons[4]		CO	CO	CO_2
Date Time	Straw Management	Straw	Stubble	mt/hectare	m/min	ha/hr	mt/hr	%	Ringleman No.	(PPM)	kg/mt	%	kg/mt	%
1971														
10-20	windrows				31.1	.61		10	.5					
10-31	windrows													
11-1	windrows	9.4	54	2.19										
11-2	spread	9.2	61	.90								.03	11.5	2.2
11-3	spread							20	1.0					
11-4	spread							15	0.75					
11-8	spread							10	0.5					
11-9 AM	spread	10[3]	61[3]	1.46	20.7	.38	2.7	8	0.4	6	.08	.01	2.8	3.0
11-9 PM	spread	10[3]	61[3]	1.46	20.7	.38	2.7	10	0.5	40	.07	.05	16.8	2.5
11-10 4 PM	windrows	10	61	1.46	16.8	.28	2.4	10	0.5	14	.38	.03	15.8	1.6
11-22 3:45	windrows	15	48	1.10[3]						13	.15	.04	9.3	3.6
11-23 2:30[1]	windrows	13	59	1.10				20	1.0	18.5	.35	.042	15.3	2.3
11-23 4:30[2]	windrows	13[3]	59[3]	1.10				20	1.0	86	1.6	.033	12.7	2.3
1972														
3-28 PM	spread	8.3	13.2	.79	21.4[3]	.39	1.5	25	1.25					
3-29 3:00	spread	8.7	20.7	1.64	26.8[3]	.49	4.0	30	1.5	1.9	.08	.001	.8	1.1
3-29 4:00	spread	9.5	12.9	1.61	26.8[3]	.49	3.9	30	1.5	6.2	.125	.04	16.0	2.1
3-29 5:00	windrows	7.6	12.0	1.55	30.5[3]	.57	4.6	40	2.0			.04	16.8	2.0
3-30 10:00AM	windrows	7.6	12.0	1.55	26.8[3]	.49	3.8					.035	18.4	1.6

[1]Tractor 600 RPM   [2]Tractor 800 RPM   [3]Estimated   [4]Expressed as PPM of C

Blanks in data indicate information not recorded primarily due to a lack of man power

(metric units)

Date	Andersen Impactor: Total Part. $\mu g/m^3 \times 10^3$ Total	Total Part. $\mu g/m^3 \times 10^3$ $<7\mu$[7]	(Particulate) $\mu g/m^3 \times 10^3$ 12% CO_2 Total	$\mu g/m^3 \times 10^3$ 12% CO_2 $<7\mu$[7]	Total Part. μg/mt straw Total	Total Part. μg/mt straw $<7\mu$[7]	Temperature Measurements: Ground Surface Temp. ^oC High	Ground Surface Low	Ground Surface Avg.	Stack Gas Temp. ^oC High	Stack Gas Avg.	Air Flow: Primary Air RPM	Primary Air m^3/min	Secondary Air RPM	Secondary Air m^3/min
1971															
10-20			1510	428	8.5	2.4									
10-31							280	125	225	538					
11-1							250	55	155						
11-2															
11-3															
11-4															
11-8															
11-9	408	108	1630	431	9	2.6						1700	792	300	1404
11-9	458	163[5]	2200	785	12	4.3	500	125	348	649		1700	792	550	2567
11-10	460	108[5]	3450	804	20	4.4	220	150	183			1400	509	600	2802
11-22		93.7		311		1.8	290	225	247						
11-23		126		602		2.3[8]									
11-23		104		540		3.0[8]									
1972															
3-28	2040	28.6													
3-29	4650	43.5	35,000	474	284	2.6	523	257	333	860	704				
3-29							309	231	260	871	371				
3-29	3890	62.3	23,400	62.3	130	2.1	678	402	563	954	427				
3-30	1429	69.6	10,600	522	60	2.9	574	565	581[6]						

5 Estimated on the basis of the average proportion of total particles on the second stage of the Anderson sampler.

6 Average of two thermocouples only.

7 Does not include particles <.43µ

8. Not included in averages on page 21.

Fall 1971 and Spring 1972 - OSU Incinerator Trials in Rice Fields
(English Units)

		Field Conditions				Operation Data			(Smoke) Stack Sampling				(Gas)		
			Moisture (%) (wet basis)		Density (dry wt.)				Avg. Smoke Density -		Hydrocarbons[4]				
Date	Time	Straw Management	Straw	Stubble	ton/acre	Speed ft/min	ac/hr	Rate ton/hr	%	Ringleman No.	(PPM)	lb/ton	CO %	CO lb/ton	CO_2 %
1971															
10-20		windrows				102	1.5		10	.5					
10-31		windrows													
11-1		windrows	9.4	54	4.92										
11-2		spread	9.2	61	2.03								.03	22.9	2.2
11-3		spread							20	1.0					
11-4		spread							15	0.75					
11-8		spread							10	0.5					
11-9	AM	spread	10[3]	61[3]	3.27	67.8	.93	3.0	8	0.4	6	.2	.01	5.6	3.0
11-9	PM	spread	10[3]	61[3]	3.27	67.8	.93	3.0	10	0.5	40	1.4	.05	33.5	2.5
11-10	4 PM	windrows	10	61	3.27	55.0	.70	2.6	10	0.5	14	4.8	.03	31.5	1.6
11-22	3:45	windrows	15	48	2.46[3]						13	.3	.04	18.6	3.6
11-23	2:30[1]	windrows	13	59	2.46				20	1.0	18.5	.8	.042	30.6	2.3
11-23	4:30[2]	windrows	13[3]	59[3]	2.46				20	1.0	86	3.2	.033	25.3	2.3
1972															
3-28	PM	spread	8.3	13.2	1.77	70[3]	.96	1.7	25	1.25					
3-29	3:00	spread	8.7	20.7	3.69	88[3]	1.2	4.4	30	1.5	1.9	.15	.001	1.5	1.1
3-29	4:00	spread	9.5	12.9	3.61	88[3]	1.2	4.3	30	1.5	6.2	.25	.04	31.9	2.1
3-29	5:00	windrows	7.6	12.0	3.48	100[3]	1.4	4.9	40	2.0			.04	33.5	2.0
3-30	10:00 AM	windrows	7.6	12.0	3.48	88[3]	1.2	4.2					.035	36.7	1.6

[1] Tractor 600 RPM [2] Tractor 800 RPM [3] Estimated [4] Expressed as PPM of C

Blanks in data indicate information not taken primarily due to lack of man power.

Fall 1971 and Spring 1972 - OSU Incinerator Trials in Rice Fields
(English Units)

Date	Andersen Impactor (Particulate): Total Part. gr/scf Total	Total Part. gr/scf <7μ [7]	Grains at 12% CO_2* Total	Grains at 12% CO_2* <7μ [7]	Total Part. lb/ton straw Total	Total Part. lb/ton straw <7μ [7]	Temperature Measurements: Ground Surface Temp. °F High	Ground Surface Temp. °F Low	Ground Surface Temp. °F Avg.	Stack Gas Temp. High	Stack Gas Temp. Avg.	Air Flow: Primary Air RPM	Primary Air CFM	Secondary Air RPM	Secondary Air CFM
1971															
10-20			0.66	.187	17.0	4.9									
10-31							536	257	437	1,000					
11-1							482	131	311						
11-2															
11-3															
11-4															
11-8															
11-9	.178	.047	0.712	.188	18	5.3						1700	28,000	300	49,600
11-9	.200	.071[5]	0.960	.343	25	8.5	932	257	659	1,200		1700	28,000	550	90,700
11-10	.201	.047[5]	1.507	.351	39	9.0	428	302	362			1400	18,000	600	99,000
11-22		.0409		.136		3.5[8]	554	437	476						
11-23		.0550		.263		4.7[8]									
11-23		.0452		.236		6.0									
1972															
3-28	.89	.0125													
3-29	2.03	.0190	15.5	.207	567	5.3	973	459	631	1,580	1,300				
3-29							589	448	500	1,600	700				
3-29	1.70	.0272	10.2	.0272	260	4.2	1,252	756	1046	1,750	800				
3-30	.62	.0304	4.66	.228	119	5.8	1,065	1049	1057[6]						

5 Estimated on the basis of the average proportion of total particles on the second stage of the Andersen sampler.

6. Average of two thermocouples only 7. Does not include particles <.43μ 8. Not included in averages on page 21

APPENDIX C

Field Observations in Barley Straw

BEMCO CYCLONE BURNER

Run No.	Notes	Speed km/hr	Speed (mph)	Fire Box Temperature °C	Fire Box Temperature °F	Fan Speed RPM
1	Blacksmoke	.99	(1.6)	817°	(1500°)	1,000
2	Fairly Clean	.87	(1.4)	803°	(1475°)	1,000
3	Some residue unburned, clean stack	.93	(1.5)	705° 803°	(1300°) start (1475°) end	1,000
4	Some residue unburned	.93	(1.5)	747°	(1375°)	1,000
5	Better burn	.93	(1.5)	885°	(1625°)	1,000
6	Chance to warm up-clean burn, no stubble left	.93	(1.5)	926°	(1700°)	1,000
7	Unburned materials	1.10	(1.8)			
8	Poor burn (too fast) (3 ton/hr)	1.68	(2.7)	604°	(1120°)	1,000
9	Fan not adjusted	1.05	(1.7)			
10	Clean, good burn-best run (2.3 ton/hr)	1.30	(2.1)	788°	(1450°	1,000

APPENDIX D

ASSUMPTIONS:

1. 37% of dry weight of fuel is carbon.
2. 97% of carbon is oxidized to CO_2.

A. Pounds of CO per ton of fuel burned:

$$\text{lbs/ton} = \frac{\%CO}{\%CO_2} \cdot \left[\frac{\left(\frac{28\ \text{lbs.CO}}{\text{mole}}\right)\left(\frac{2000\ \text{lbs}}{\text{ton}}\right)}{\left(\frac{12\ \text{lbs C}}{\text{mole}}\right)\left(\frac{1\ \text{lb fuel}}{.37\ \text{lbs C}}\right)\left(\frac{1\ \text{lb. C}}{.97\ \text{lb. C burned to } CO_2}\right)}\right]$$

$$\text{lbs/ton} = \frac{\%CO}{\%CO_2}\ (1675)$$

B. Pounds of hydrocarbons per ton of fuel burned:

Hydrocarbons expressed as carbon in hexane or $\frac{C_6H_{14}}{6}$ or $C_1H_{2.33}$

$$\text{lbs/ton} = \frac{\text{ppm C}}{\%\ CO_2}\left[\frac{\left(\frac{14.3\ \text{lbs}\ C_1H_{2.33}}{\text{mole}}\right)\left(\frac{2000\ \text{lbs}}{\text{ton}}\right)\left(\frac{10^{-4}\ \%}{\text{ppm}}\right)}{\left(\frac{12\ \text{lbs C}}{\text{mole}}\right)\left(\frac{1\ \text{lb fuel}}{.37\ \text{lb C}}\right)\left(\frac{1\ \text{lb C}}{.97\ \text{lb C burned to } CO_2}\right)}\right]$$

$$\text{lbs/ton} = \frac{\text{ppm C}}{\%\ CO_2} \cdot [.0857]$$

C. Pounds of particulates per ton of fuel burned:

$$\text{lbs/ton} = \frac{\frac{\text{gr}}{\text{scf}}}{\frac{\%CO_2}{100}} \cdot \left[\frac{\left(\frac{1\ \text{lb}}{7000\ \text{gr}}\right)\left(\frac{2000\ \text{lb}}{\text{ton}}\right)}{\left(\frac{12\ \text{lbs C}}{\text{mole}}\right)\left(\frac{1\ \text{mole}}{359.1\ \text{ft}^3}\right)\left(\frac{1\ \text{lb fuel}}{.37\ \text{lb C}}\right)\left(\frac{\text{lb C}}{.97\ \text{lb C burned to } CO_2}\right)}\right]$$

$$\text{lbs/ton} = \frac{\frac{\text{gr}}{\text{scf}}}{\%CO_2} \cdot [307]$$

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gr - grains
scf - standard cubic foot
lbs/ton - pounds per ton

CO - Carbon Monoxide
CO_2 - Carbon Dioxide
C_6H_{14} - Hexane

APPENDIX D (Continued)

*97% of Carbon is estimated to be oxidized to CO_2 as follows:

Ash and chloroform insoluble particulates; 475 lbs/ton @ 8% C	= 38 lbs.
Hydrocarbons, 1 lb./ton @ 84% C	= 1 lb.
Carbon Monoxide, 30 lbs/ton @ 43% C	= 13 lbs.
Chloroform-soluble particulates, 6 lbs/ton @ 80% C (approx.)	= 5 lbs.
	57 lbs.

$\frac{57 \times 100}{2,000}$ = 3 % not oxidized to CO_2

Therefore: 97% C oxidized to CO_2

APPENDIX E

Rice Acreage Harvested in California 1965-1972[7]

Year	Acres
1965	327,000
1966	360,000
1967	360,000
1968	432,000
1969	389,000
1970	331,000
1971	331,000
1972	331,000
AVERAGE	362,000
1973 (estimated)	400,000

Some rice residue is not burned. Therefore, a figure of 300,000 acres of residue was used as an approximation for the number of acres that would have to be burned by incinerator.

APPENDIX F

Aerodynamic Particulate Size Distributions

Equivalent Aerodynamic Diameter at 50% collection efficiency (microns)		Percent of Total Weight Headfire (2 burns)	Backfire (2 burns)
1973 Riverside Data (Weathermeasure Hivol Cascade Impactor)			
Total Collection			
Stage 1	8.2 to 00	2	4
2	3.5 to 8.2	3	5
3	2.1 to 3.5	3	3
4	1.0 to 2.1	5	5
5	.5 to 1.0	10	9
6	.01 to .5	78	78
Particles >.43μ &<7μ			
	3.5 - 7.0	7	10
	2.1 - 3.5	14	10
	1.0 - 2.1	29	30
	.50 - 1.0	36	40
	.43 - .50	14	10

Incinerator (Andersen Cascade Impactor)			
Total Collection		1972 Spring (4 runs)	1971 Fall (3 runs)
Screen 00 →→→→→→→		70%	69.1%
Stage 0	11 to 00	10.7	3.9
1	7 to 11	3.2	3.1
2	4.7 to 7	4.4	3.0
3	3.3 to 4.7	5.1	3.5
4	2.1 to 3.3	3.4	2.5
5	1.1 to 2.1	1.7	4.5
6	.65 to 1.1	.64	4.4
7	.43 to .65	.89	5.9
Particles >.43μ & <7μ			
	4.7 to 7.0	27.3	12.6
	3.3 to 4.7	31.7	14.7
	2.1 to 3.3	21.1	10.5
	1.1 to 2.1	10.6	18.9
	.65 to 1.1	4.0	18.5
	.43 to .65	5.5	25.5