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UTILIZATION OF METHANOL IN STATIONARY SOURCE COMBUSTION

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UTILIZATION OF METHANOL IN STATIONARY SOURCE COMBUSTION

by

A. C. S. Hayden*

ABSTRACT

The paper is concerned with the potential use of methanol as a fuel substitute in stationary source combustion. Methanol should only be considered for replacing premium fuels, defined as No. 2 or ligher oil or natural gas. Fuel properties of methanol are presented in the form of combustion charts, illustrating the high heat loss potential with methanol because of hydrogen in the fuel.

In domestic heating, methanol could be substituted for No. 2 oil in existing equipment, with minor modifications, resulting in improved fuel efficiency because of reduced effective firing rate. Problems exist in terms of low flash point and toxicity. In commercial and industrial applications, little or even negative end use efficiency gain could result from methanol substitution. Methanol does offer promise as a potential fuel for the gas turbines on the Trans Canada natural gas pipeline.

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METHANOL USE IN STATIONARY SOURCE COMBUSTION

1.0 Introduction

The use of methanol in stationary source combustion has the advantage over its use in automotive applications that little or no problem is created by small amounts of impurities in the methanol, such as water. Most burners capable of burning methanol will also be able to burn the methanol-water mix.

In selecting the type of stationary source for methanol firing a number of factors should be examined. Firstly, methanol should be considered only where a fluid fuel (liquid or gas) is now being burned. Secondly it should only be considered where it can displace a premium fuel, defined as a No. 2 or ligher fuel oil, or a gaseous fuel. Presentations from the oil companies as well as other private discussions, indicate that there will be a sufficient quantity of residual fuel oil as a by-product of refining, and that markets for this high-energy low-quality fuel should be kept open and allowed to grow at the expense of premium fuels, keeping in mind the future use of direct burning of lower-grade solid fuels (coal or wood) probably in fluidized-bed combustors.

Another consideration should be that methanol should provide some technical, capital equipment, and/or efficiency benefits (or at least, no efficiency decrease relative to the fuel it replaces. Coupled to that is the criterion that this benefit should not arise at the expense of incurring a severe economic penalty. However, detailed economic analysis is beyond the scope of this report, because of the paucity of technical work done in the stationary source area.

Finally, the choice should be made on the basis of freeing-up some desirable fuel for other uses. After tests conducted by the incumbent on the new high-speed diesel automobiles (50-75 mpg with the Volkswagen Diesel Rabbit), it appears that release of some of the distillate portions of the crude-oil barrel will be required for the diesel, with its immensely superior fuel economy, to achieve the significant inroads anticipated into the automotive market in Ontario and Canada.

2.0 Fuel Properties

In order that the combustion properties of methanol can be judged in relation to those of premium fuels which it may replace, sets of combustion curves for methanol, No. 2 fuel oil and natural gas are given in Appendices B, C and D respectively. These curves may be used to size gas-handling systems for fuel-burning installations, to design burners and furnaces, to select equipment for draft systems on boilers, and to determine efficiency of operation. The graphs show the quantities of combustion air required and flue gas produced:

(a) per fuel unit for a range of temperature and excess air conditions, and

(b) the heat losses resulting from the combustion of the fuel for a range of conditions.

Prior to each set of curves, an analysis of the particular fuel is given, along with its specific gravity and its heating value. The heating value given, as commonly used in North American practice, is the Higher Heat Value (Gross Calorific Value) and all work in this report is based on this value.

The sets of curves for No. 2 fuel oil and natural gas (in Appendices C and D) are taken from references 2, and 3, respectively. These references give detailed explanations of the many uses for these curves.

2.1 Explanations of Combustion Data Graphs

2.1.1 Explanation of Figure 1 - Combustion Data, Weight Basis

In each set of graphs, Figure 1 shows, the combustion of one unit of fuel, the weight of dry combustion air required and the weights of dry flue gas and total flue gas produced, versus the per cent of total combustion air. Total combustion air is defined as per cent of stoichiometric air, or per cent excess air plus 100. The calculations were made on a dry air basis, i.e., moisture in the air was neglected because its effect is usually less than one per cent. Dry flue gas represents the moisture-free components of the flue gas, namely CO_2, O_2 and N_2 while total flue gas represents the foregoing components plus the moisture resulting from combustion of hydrogen, but excluding

Moisture from combustion air. Flue gas analysis may be related to total combustion air by either the CO_2 curve or the O_2 curve.

2.1.2 Explanation of Figure 2 - Combustion Data, Volume Basis

In each set of graphs, Figure 2 shows, for a range of temperatures, the volume of combustion air required and flue gas produced per unit of fuel burned. As in Figure 1, these are plotted against total combustion air. For most purposes, such as the sizing of induced draft fans, the total volume of flue gas is required, and this is plotted for a range of temperatures. However, there is an occasional requirement for the volume of dry flue gas; therefore, a curve giving this information for a temperature of 32°F has been included. The volumes shown are for an atmospheric pressure of 29.92 in. Hg.

2.2 Explanation of Heat Loss Graphs

2.2.1 Explanation of Figure 3 - Dry Flue Gas Loss

In each set of graphs, Figure 3 shows the heat loss, in per cent of fuel input, represented by the sensible heat in the dry flue gas leaving the system. This loss is dependent upon the excess air level and the difference in temperature between the flue gas and the combustion air; therefore, heat loss has been plotted against total combustion air for a range of temperature differentials. CO_2 and O_2 curves have been included to conveniently relate flue gas analysis to total combustion air (excess air).

2.2.2 Explanation of Figure 4 - Hydrogen Loss

Figure 4 shows the heat loss, in per cent of fuel input, due to moisture in the flue gas formed from the combustion of hydrogen. Being based on gross calorific value, the loss consists of the heat of evaporation plus superheat; hence, for a fixed hydrogen content of fuel, it depends upon stack temperature and combustion air temperature.

2.2.3 Explanation of Figure 5 - CO Loss

Figure 5 shows the heat loss, in per cent of fuel input, due to carbon monoxide in the flue gas, resulting from incomplete combustion. This loss increases with increasing CO concentration and with decreasing CO_2 concentration.

2.3 Hydrogen Loss

It is particularly instructive, when considering these fuels, to examine the hydrogen loss, which is essentially a fixed loss for any particular fuel. Taking standard conditions of a stack temperature of 500°F and a combustion air temperature of 70°F the hydrogen loss for No. 2 fuel oil, natural gas and methanol is 7.6%, 11.7% and 14.5%, respectively. It has been recognized that in a similar situation, natural gas fired boilers will be 2 - 4% less efficient than boilers fired by fuel oil. Methanol could thus be anticipated to yield lower efficiencies than either of these fuels in conventional stationary source utilization.

3.0 Stationary Source Utilization

3.1 Domestic Heating

One of the major use areas of distillate oil in Canada is the domestic heating market. The Canadian Combustion Research Laboratory (CCRL) in co-operation with the Office of Energy Conservation and some of the provinces, notably Ontario, has embarked on a major program to reduce oil consumption in domestic heating, through an upgrading in the level of servicing, the installation of retrofit equipment such as burner retention heads, reduced nozzle sizes, positive chimney dampers and the development of new highly efficient burner and heat transfer systems. These modifications, coupled with the federally sponsored retrofitting home insulation program will reduce demand growth in this area significantly.

From the point of view of methanol use in the area of domestic heating, the retrofitting of a good retention head (Beckett type) on a conventional oil burner produces a burner which appears to be able to burn methanol at a relatively high efficiency. Preliminary CCRL laboratory tests have yielded a steady-state efficiency of 77%, which is slightly above the average efficiency of 73.5% for existing No. 2 fuel oil-fired equipment. It should be realized that most domestic furnaces are oversized for existing housing. Because of this, furnaces are either off or in an inefficient transient portion of their operating cycle a great deal of the time. Figure 1 shows a typical graph of furnace stack temperature. It is seen that equilibrium is not reached until some 15 minutes after the furnace/burner comes on. Most furnaces only rarely achieve equilibrium. As the retrofitting of insulation becomes more complete, this problem will become even more serious. The introduction of methanol could counteract this effect, and indeed lead to improved (reduced) seasonal fuel utilization. The potential energy savings are indicated on pages 3 and 4 of the attached paper (labelled Appendix A), "Oil Conservation in Home Heating", where a reduction in firing rate of 15% leads to a 10% fuel saving, even where the steady-state efficiency has been slightly reduced. The problem with continued firing rate reduction in domestic oil burners, as they now exist, is that operation below 0.65 gallons of No. 2 fuel oil per hour is most unsatisfactory because of nozzle characteristics. By substituting methanol, regimes of operation as low as 0.33 gallons of No. 2 fuel oil equivalent become possible because of the much lower energy content per unit volume of methanol.

Aside from the retrofitted retention head, which we can assume will be in place, a smaller blower wheel (squirrel cage) will have to be inserted. Problems will definitely exist with the present oil pump unit, primarily because of the poor lubricity of methanol. Laboratory tests at CCRL have indicated that pump failure could occur within 100 hours of operation (1000 hrs per heating season is present burner operating time). If a pump is redesigned to overcome this lubricating problem, components should also be examined to ensure that they will not be subject to methanol-water corrosion.

In the CCRL tests of a domestic burner fueled with methanol the resulting flame was yellow, not transparent blue as expected. If this is the case in general, then the existing cadmium photocell flame sensor can be employed. The fuel handling system, from the fuel tank to the burner, is usually copper tubing and connectors, and should not show any methanol attack.

The fuel tank itself, with the vent to atmosphere outside the house, may pose a problem, but the addition of a check valve may be an adequate solution. The vent should also be fitted with a flame arrestor. In addition, it would be desirable to add a convective air condenser and an absorbent bed in the vent line, such as used for vapour control on automobiles. The delivery pump on the truck would have to be changed and possibly also the pump line and receptor, to ensure the proper fuel is bunkered when the house tank is being filled.

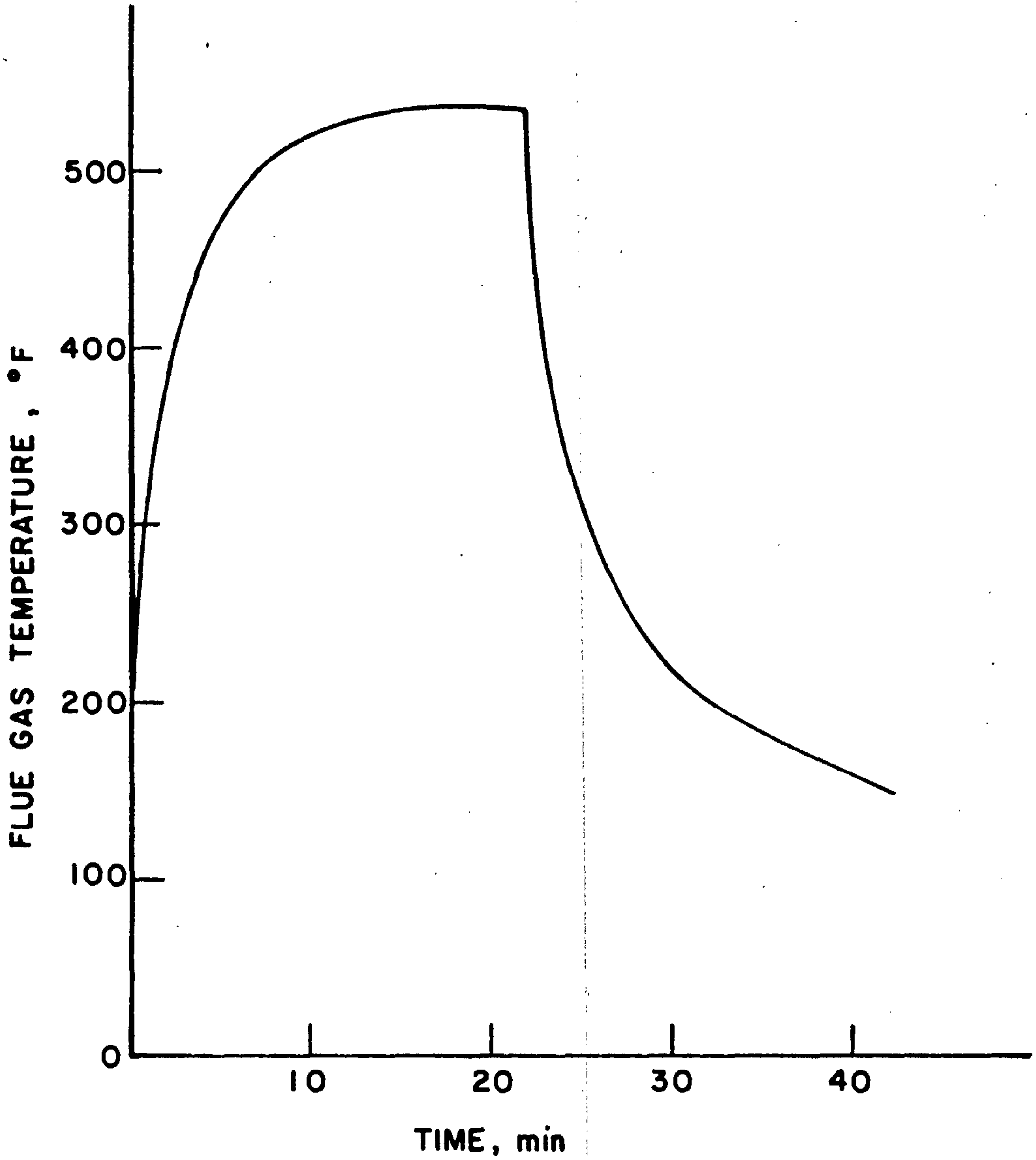

Figure 1. Flue gas temperature change during transient furnace operation at 1.0 gph nozzle. (No.2 fuel oil).

An explosive mixture might result from a spill which, with a source of ignition such as the burner or a carelessly discarded cigarette, might result in considerable damage. In addition, if the burner safety controls were not adequate, failure of the furnace to light initially when cold, followed by subsequent ignition, could result in an explosion. Thus, special care would have to be taken with the controls during annual servicing.

Since the maximum exposure level for long periods of time is below the odour detection level, a householder could be in a potentially hazardous situation without knowing it. Odourous chemicals could, however, be easily added to methanol to alleviate this situation, as sulphur is added to natural gas. A complete public education program would have to be undertaken to acquaint the public with the potential results of misuse. Particularly for the serviceman, the exposure hazard is very real and he would have to take special precautions in these activities.

As far as the changes required to allow methanol to be burned in domestic oil furnaces are concerned, it is assumed that the retrofit retention head has already been paid for by fuel oil savings and should not be charged to methanol. Modifications should be charged to methanol include a new self-lubricating fuel pump, any elastomer seals, the tank-venting check valve and charcoal filter, a new squirrel-cage blower wheel, and a pro-rated portion of the tank-truck modifications - the pump and the nozzle. It is estimated that all of these could be achieved at a cost of $200 ±25%, including three man-hours labour.

3.2 Commercial Boilers

Boilers designed to fire No. 2 or heavier fuel oil have both radiative and convective heat transfer passes. The higher intensity burners fould in these applications will definitely lead to a transparent blue flame with methanol; hence, there will be a serious loss in heat transfer ability and efficiency. For boilers designed specifically for natural gas, there will only be convective heat transfer passes, and hence efficiency will not be so seriously affected. Even so, as discussed in Section 2.3, for new designs it should be recognized that, for any well-designed system, efficiency will always be two to four per cent lower for natural gas than for oil, because of the higher hydrogen loss.

Results on one of the few applications of methanol to large boilers indicate a loss in efficiency of 3%, relative to natural gas. This is primarily due to the higher hydrogen loss for methanol than for natural gas, let alone for No. 2 fuel oil.

The one time when end-use efficiency might not suffer in applying methanol to commercial boilrs would be in off-season boiler use, when the load demand is low. As seen in Figure 2, showing efficiency vs load for CCRL tests on two boilers fired with both natural gas and No. 2 fuel oil, maximum efficiency in most boilers occurs somewhere between 60% and 80% of rated output, falling off slightly above this level. However, at low firing rates, the efficiency is often much worse, anywhere from 3% to 10% lower because of poor combustion air control. Using methanol, with its implicit derating capability, during the periods of low demand, could allow the boilers to run at a higher firing rate (in terms of gallonage) and thus be slightly more efficient. This application would require a second fuel-storage and perhaps, fuel-handling system, so the cost of equipment could outweigh the slight efficiency benefit. It is estimated that, for a medium sized boiler in the range 20,000 pounds of steam per hour, conversion costs could be in the range of $10,000 to $20,000. New fuel pumps, non corrodable seals, etc., would all be required.

For smaller commercial boilers of the on-off (intermittent) type, substitution of methanol during periods of lower demand, such as reheat for air conditioning during the summer, would result in another beneficial derating, where the burner would be on for longer periods of time; the boiler would thus be in equilibrium longer and in the inefficient transient phase less, and fuel consumption might be reduced. Problems to be contended with and equipment to be modified would be similar to the domestic situation.

The advantages of the application of methanol in those commercial steam-raising plants with full-time stationary engineers are that trained personnel would be operating the equipment, to prevent or combat any hazards due to flammability or toxicity, and that large single users would minimize distribution problems.

Large plants should now be burning a low grade fuel, either a heavy fuel oil or coal; where this is so, conversion to methanol should be avoided.

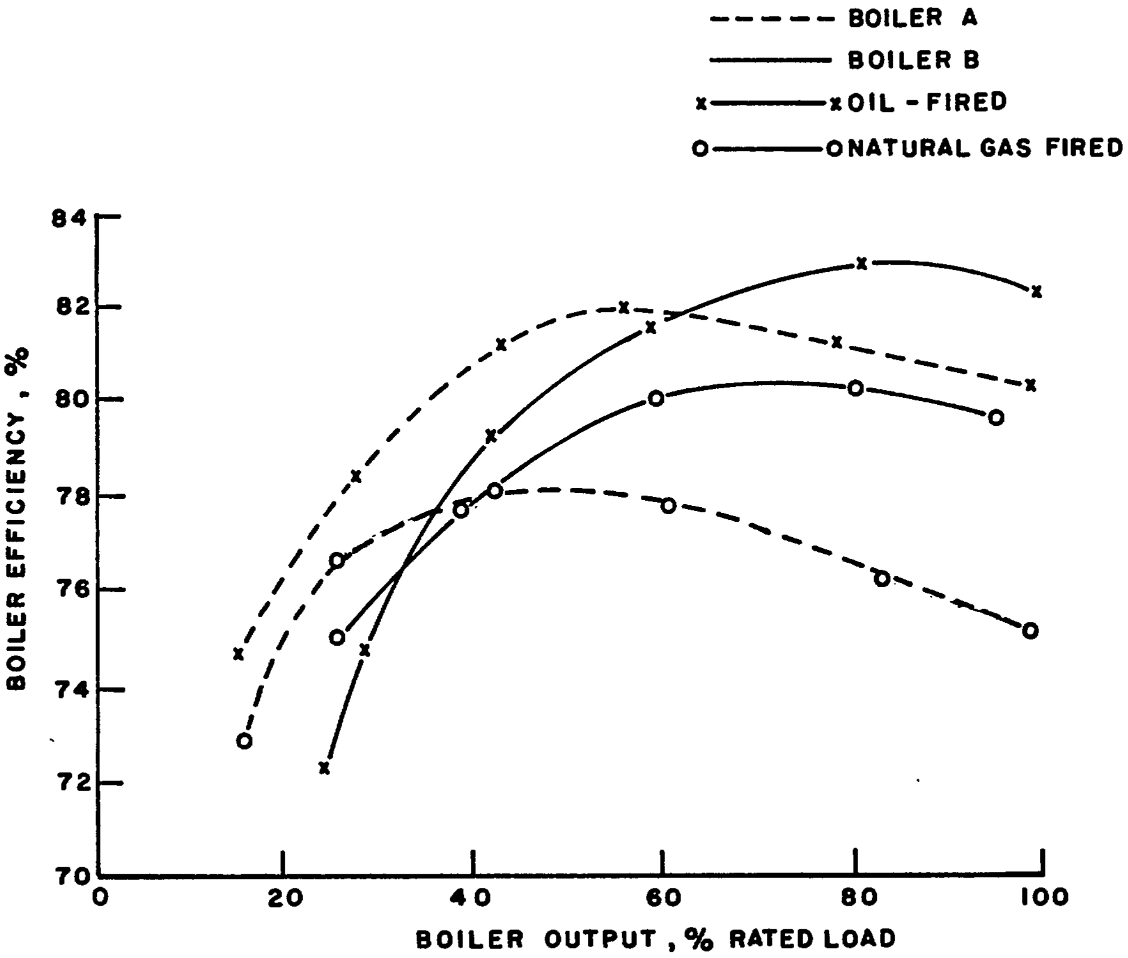

Figure 2. Boiler efficiencies as a function of boiler output

3.3 Industrial Processes

In this area, any direct-fired process makes use of the radiant properties of an oil flame to an even greater extent than a boiler, so that methanol introduction in such industrial applications would have a significant negative effect on process efficiency. However, it has been brought to the author's attention that certain applications in the mining/metallurigical industry do require the use of premium fuels, No. 2 fuel oil or natural gas, without the radiative requirements. In such areas, methanol, with competitive price and delivery along with reliable performance, could be a potential alternative.

In those industrial applications such as heat-treating, drying or paint-baking where oil use necessitates indirect-firing, methanol with its soot-free combustion could allow direct-firing into the process, at a significant gain in energy efficiency. For example, direct-fired baking ovens are about 30% more efficient than indirect-fired ovens.

Sizing of the storage and fuel handling equipment would have to be doubled, as well as burner throughput, so that no derating of the process would occur. Self-lubricating pumps and non-elastomer seals would be required because of the methanol properties.

In such industrial processes, trained personnel would be operating the equipment and would be able to prevent or combat any hazards due to flammability or toxicity, engineers would be almost immediately available to solve major problems, and large single users would minimize distribution problems with methanol.

Large industrial processes should now be burning, or should be encouraged to burn, a low grade fuel, either heavy oil or coal. It has been suggested that the pulp and paper industry might be a user of methanol from wood. From the point of view of energy efficiency, they would be much better off burning the wood directly, either conventionally in a large boiler or even better, in the coming generation of extremely highly efficient fluid-bed combustion systems.

3.4 Gas Turbines

The American Petroleum Institute, in their Task Force on methanol, (reference 5) concluded that one of the most attractive potential uses for methanol would be in stationary gas turbines. In the United States, where the use of gas turbines for electrical power generation is widespread, there might well be justification for its use in the utility area. In Canada, where the generation of electricity by gas turbines is quite uncommon, fostering this idea might lead to an increased number of these units, at an efficiency penalty of nearly 50% relative to coal-fired thermal stations.

The two areas where gas turbines are now relatively common in Canada are in aircraft engines and in fossil fuel pipelines.

For aircraft, weight is a prime consideration. Since methanol has only half the energy density of jet fuel, twice as much fuel would have to be carried for the same run, at a severe loss in payload.

The other application, fossil fuel pipelines, appears to be favourable for the use of methanol as a substitute fuel. It has been recognized that a significant quantity of our premium energy is used in transporting crude oil and natural gas from Alberta to the main use area of Central Canada (Ontario). In fact, it has been stated that as much as 10% of the energy in natural gas is lost in its transport. From Ontario's point of view this could amount to 6% of Ontario's gas consumption. From tests reported in reference 6, efficiency does not appear to suffer when methanol is substituted for oil in a turbine, and might well even appreciate when methanol is substituted for natural gas. In this reference, problems were not encountered with the fuel pump because of the short (12-hour) duration of the test and the fact that some 30W oil was fed in with the methanol to lubricate the pump. It is anticipated that the pump would have to be changed to one that did not require the fluid fuel to provide lubrication, as previously discussed. Again, problems would likely exist with present seals which could be attacked by methanol.

Certainly the release of the natural gas now used in the pipelining would be of great benefit. It should be realized, however, that savings may not be as great as they now appear, because there is evidence that the pipeline companies are now embarking on a serious energy conservation program in their lines, so that by the time that methanol is available, consumption per unit may have been reduced significantly.

4.0 Conclusions and Recommendations

1. Methanol does appear to offer efficiency advantages in oil-fired domestic heating using present equipment with only minor modifications, assuming widespread retrofitting of good retention heads in the next few years. If this use is applied, distillate will be released for the efficient diesel automobile. However, before methanol can be implemented more safety precautions must be taken to counter the flammability and toxicity problems associated with this fuel.

2. In the commercial sector, the only end-use efficiency gain which might arise would be in off-season use, allowing boilers to run at higher firing rates.

3. In the industrial sector, methanol might well substitute for premium fuels of oil and natural gas. If methanol substitution for oil allows direct firing instead of indirect firing of a process, significant efficiency gains could result. Problems in the handling and utilization of methanol would be minimized by trained operating personnel; this would be the case for large sized commercial installations.

4. Substitution of methanol for natural gas in gas turbines in the natural gas pipeline would allow an additional substantial quantity of this premium fuel into the market.

5. Large scale installations now burning low grade fuels, residual oil, coal and wood, should not be considered for methanol.

6. Other large individual users for whom methanol is being considered should be examined for the possibility of burning the wood directly, using the developing efficient technology of fluidized-bed combustion.

7. In any stationary source use of methanol, there will be the requirements for the development of a reasonably priced self-lubricating fuel pump and for an examination of the fuel handling system for any materials which would be subject to methanol attack.

8. It should be recognized that very little test data on actual operating performance with methanol exists in the stationary source area. More tests should be conducted in those areas which appear to offer benefits before any final decision on its application is made.

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APPENDIX A

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Oil Conservation in Home Heating

Field studies of the oil consumption characteristics of oil-fired residential heating systems have been carried out in several homes in a severe winter climate. Daily recording of the fuel consumption, cycling frequency and cycle length allowed the data to be used in conjunction with hourly meteorological records to establish baseline consumption patterns for comparison with consumption levels measured during the use of selected residential oil conservation techniques. Improved burner performance and overnight thermostat cutback are each shown to offer greater fuel savings than the use of a positive chimney damper designed to minimize "off" cycle losses.

Introduction

The use of energy in the forms of electricity and heating fuel in Canadian homes represents about one-fifth of the total national consumption. Fuel conservation in oil- or gas-fired residential heating equipment is, therefore, one area where absolute savings of a significant magnitude can be made and where direct effects are immediately perceived by the homeowner as dollar savings. Perhaps more important is the knowledge of a personal contribution to a national energy conservation policy.

A major difficulty in establishing possible fuel savings with residential heating equipment is the lack of reliable experimental data that can be used to substantiate the claims made for many fuel conservation techniques. Furthermore, if accurate predictions are to be made, the data should be capable of extrapolation to the wide range of climatic conditions, living habits and construction practices that are encountered across a subcontinent. This paper describes a series of field experiments which have been carried out in selected homes to evaluate several well-publicized fuel conservation strategies and to establish the relative merits of these strategies. The investigation was carried out in support of the National Fuel Conservation Policy.

The test homes, located in the Ottawa area, all used oil-fired heating equipment which occupies a dominant position in the Canadian home-heating market. The typical winter which these homes experience amounts to over 4000 Celsius degree days (below 18°C) with a minimum temperature of −30°C, a winter average temperature of −2°C and a typical total snowfall of 250 cm.

The Experimental Program

Records of the daily fuel consumption in five homes, selected for these systems analyses, have been accumulated over two consecutive winters (1974/75 and 1975/76). A brief description of the homes is given in Table 1.

The fuel consumption and cyclic operation of the heating system in each home was monitored with three digital-display meters as follows:

1. A volumetric fuel-oil meter (±0.01 Imperial gallons), which was installed in the oil supply line to the burner;
2. a total elapsed-time indicator (±0.1 hr), which was connected across the power supply to the burner and which displayed total burner operating time; and
3. an event counter, which was connected across the power supply to the burner and displayed the number of burner operating cycles.

The home owners were provided with data sheets on which the displays from the three meters were recorded twice daily (generally at 07.00 and 19.00 hr) together with any additional commentary on disturbances to the normal domestic routine. The use of open fires or a week-end absence with its attendant thermostat cutback were

Table 1 The experimental homes

Description	Type	Floor Area of Heated Space	Type of Heating	Standard of Insulation
Home A	Two storey	230 m^2	Warm-air	High
Home B	Two storey	230 m^2	Warm-air	Poor
Home C	Two storey	160 m^2	Warm-air	Average
Home D	Bungalow	110 m^2	Hot-water	Average
Home E	Bungalow	170 m^2	Warm-air	Average

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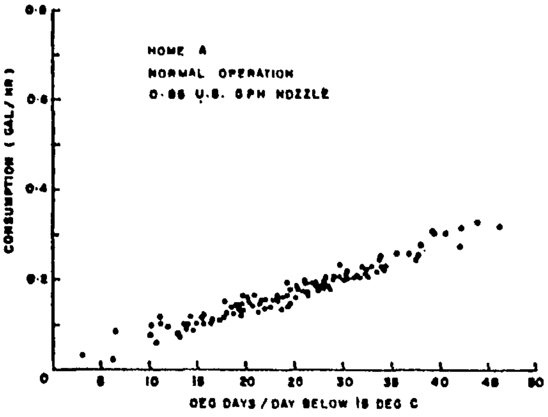

Fig. 1 A typical data plot

typical disturbances that might have had short-term effects on fuel consumption.

Throughout the course of the experiment, periods of time were designated as representing "normal" operation for each home; during these periods each control thermostat remained at a constant set-point of the home-owner's choice. The time periods were chosen to give fuel consumption data across the complete range of external (outdoor) temperatures which might be encountered in an Ottawa winter.

Weather data provided by the Atmospheric Environment Service at Ottawa International Airport included hourly temperature readings which allowed the accurate calculation of a mean temperature for any selected time period. The degree-day record for a number of years showed that for the period from October to April the average-degree day accumulation (relative to 18°C) was 4260 Celsius degree days and the mean temperature throughout the same period was −2°C. Although some heating is required outside this time period, it contributes little to the total fuel consumption and unduly biases the average winter temperature to a higher level. The studies were, therefore, restricted to the period between October 1st and April 30th.

The Experimental Data

The steady-state heat loss from a home can be regarded as a linear function of the temperature difference between the internal and external air temperatures; it is recognized that the external air temperature can be modified to take account of solar radiation by using the sol-air temperature. This technique has not been applied to the data presented in this paper.

The data from the monthly log sheets was matched with the hourly temperature readings to give an average external air temperature for the time period between recorded data points. This average temperature was then converted to degree days below 18°C and used as the abscissa in graphical presentations with ordinates such as fuel consumption (Imperial gallons/hr), burner "on" time (hr/hr) and cycles/hr. The regularity of readings provided by the home owners was good and allowed data to be obtained throughout both winters with the understandable exception of a few days between December 29th -January 4th.

The results presented in this paper are based on readings taken at 24-hr intervals and do not, therefore, illustrate effects due to daily temperature variations. A representative plot of data points is shown in Fig. 1; the scatter reflects the situation in the real world where several factors are beyond experimental control or numerical correction. These factors include domestic traffic patterns, the use of drapes on an irregular basis and changes in occupancy rate. Other factors such as solar heat gain and wind chill are amenable to numerical correction and preliminary studies of these corrections are now being undertaken.

Linear equations were fitted to all the experimental data obtained during discrete parts of the experimental program and the 95 percent confidence limits obtained by standard statistical techniques. With a single exception, it was found that polynomials of higher order did not substantially improve the correlation coefficient above that of the linear equation. The exception occurred in part of the data from Home B when the heating system was unable to maintain the thermostat set-temperature during very cold weather. The furnace was operating continuously and further drops in external temperature could not increase the fuel consumption, the burner operating time or the cycling frequency. Consequently, the linear correlations used were considered to be fully justified.

Using this simple data recording and reduction technique, the following variations in furnace operation and burner hardware were studied during the course of the two test winters:

Thermostat operation : Moderate overnight cut-back
Severe overnight cut-back
Reduced "off" cycle losses: Positive chimney damper
Reduced firing rate
Burner performance : Retention-head burner
Prototype blue-flame burner

The Effect of Insulation

The reduction of heating load and fuel consumption by improvement in insulation standard is an acknowledged conservation technique. This effect and a secondary effect of improved insulation are shown in Fig. 2 where the hourly fuel consumption, as a function of external temperature, is compared for two homes of equal floor area having closely similar orientation and exposure. Home A was insulated to a standard better than that required for electrically heated homes, whereas Home B incorporated only conventional insulation.

In both cases the hourly fuel consumption followed the external temperature variation without any significant thermal storage effect.

Home A showed an average fuel consumption of 0.2 I gph, whereas the poorer insulation of Home B increased this figure to 0.3 I gph during the test period illustrated. It is also noticeable that the amplitude of the swings in the hourly fuel consumption is much smaller

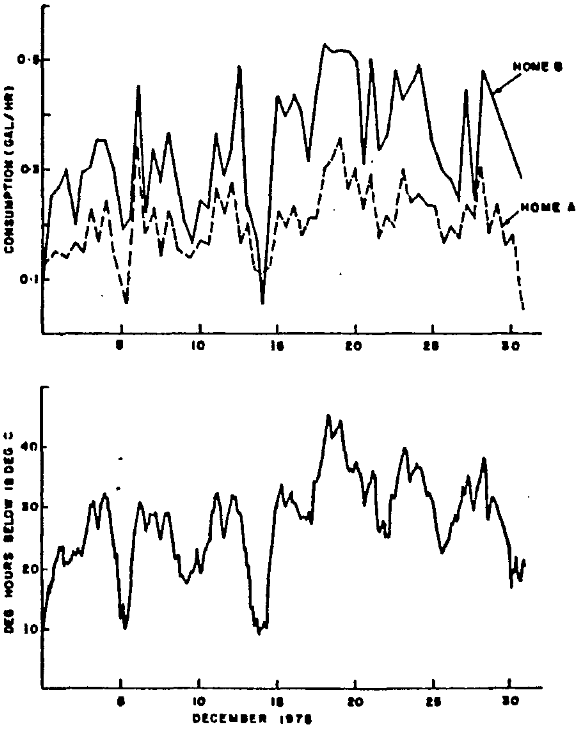

Fig. 2 The effect of external temperature on fuel consumption: Homes A and B

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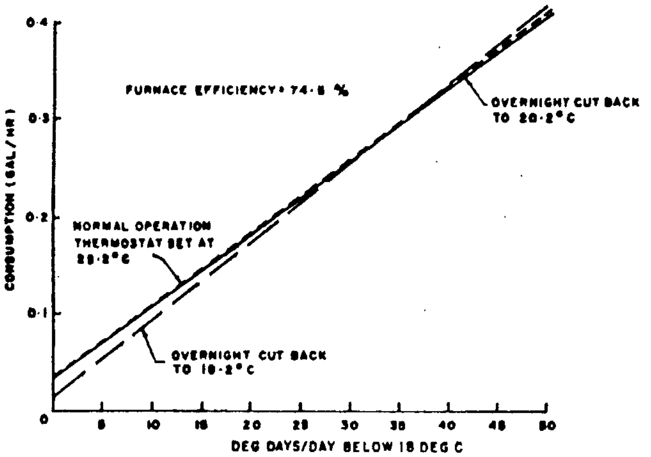

Fig. 3 The effect of two levels of overnight thermostat cut-back on fuel consumption: Home E

in the well-insulated home. As a result, burner cycling frequency remained constant over a much wider range of external temperature and this was reflected in smaller swings in internal temperature and closer control of the internal comfort condition.

The Effect of Overnight Thermostat Cut-Back

During the program, the homeowners were requested to vary their usual pattern of thermostat operation to give information on the effects of overnight thermostat cutback on fuel consumption. To minimise interference with normal domestic routines, the overnight period was defined as being between "going to bed" and "getting up."

Typical results from two homes are illustrated in Figs. 3 and 4. Home D was one in which the savings due to overnight thermostat cutback were small and, although a fuel saving was indicated, it fell within the confidence limits of the normal (no cutback) data. Fig. 3 shows data from Home E in which two levels of cutback from a base of 22.2°C (72°F) were practised. An overnight cutback of 2°C (4°F) produced no appreciable differences in fuel consumption, whereas a 4°C (7°F) cutback to 18.2°C produced reductions in fuel consumption at all external temperatures above −22°C. No data were recorded at temperatures below this level where the early morning heat requirement had increased presumably to the point of negating any fuel savings that had accrued during the overnight cutback.

Fig. 4 shows the effect of a cutback in Home B where the daytime thermostat setting was 21.1°C (70°F) and the cutback was to 16.1°C (61°F). In this case, the reductions in fuel consumption were to levels outside the confidence limits of the normal (no cutback) data and the two consumption lines were marginally divergent indicating that a fuel saving would accrue from overnight cutback at all external temperatures.

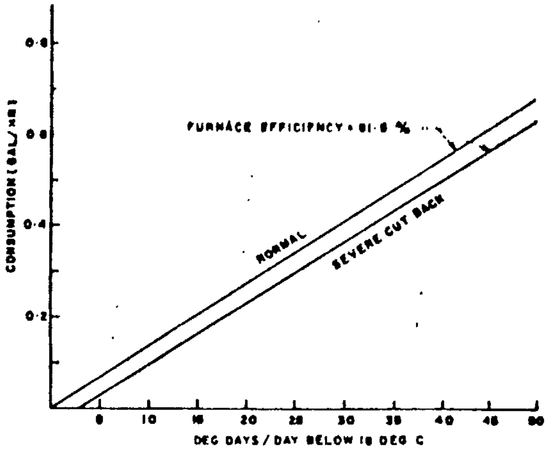

Fig. 4 The effect of severe overnight thermostat cut-back on fuel consumption: Home B

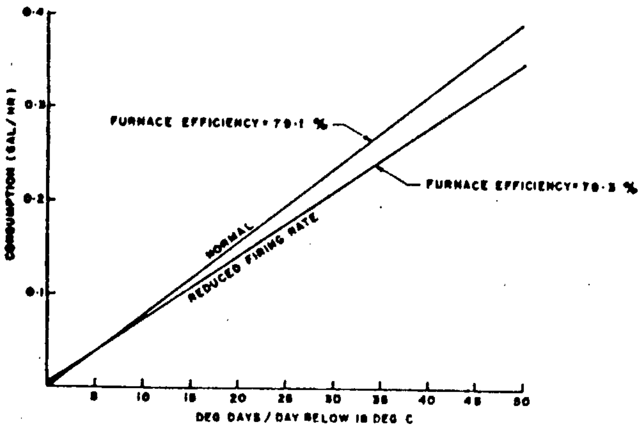

Fig. 5 The effect of reduced firing rate on fuel consumption: Home A

Reduction of Off-Cycle Losses

Heat losses during the "off" cycle can severely reduce the overall home heating efficiency. These losses occur by two mechanisms:

1 heat stored in the furnace structure can be lost, by natural convection, up the chimney, and

2 basement air at indoor temperatures allows the chimney to provide a ventilation loss with a driving force determined by the temperature difference between the indoor and outdoor temperatures.

In this program two methods of reducing this "off" cycle loss were investigated. The first was to reduce the burner firing rate and thus increase burner operating time for a specific heat demand; the second was to restrict flow through the chimney by use of a positive chimney damper, safety-interlocked with the burner operation.

The Effect of Reduced Firing Rate. The effect of reduced firing rate in one home is clearly illustrated in Fig. 5. In this case the reduction of firing rate from 1.00 US gph to 0.85 US gph was accompanied by a decrease in furnace efficiency from 79.1 to 78.3 percent. Despite this, the lower firing rate gave higher cyclic efficiencies which more than offset the reduced steady-running efficiency.

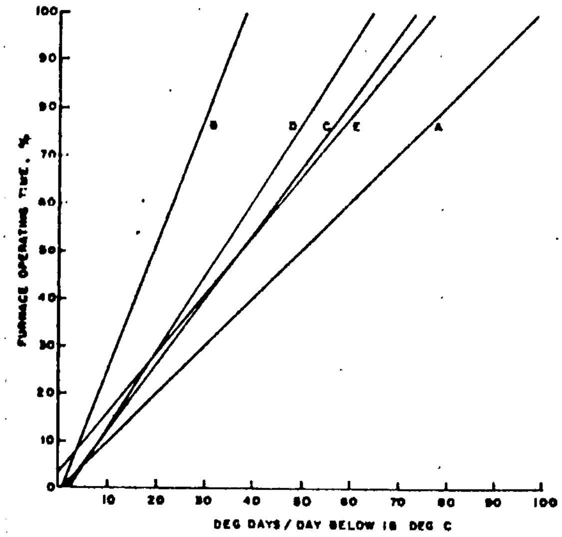

Fig. 6 The effect of external temperature on furnace operating time

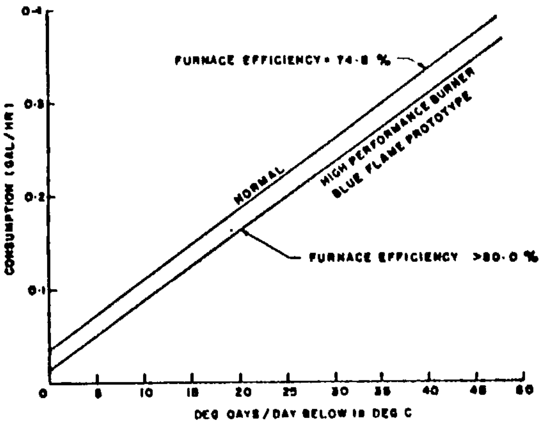

Fig. 7 The effect of improved burner performance: prototype blue flame burner, Home E

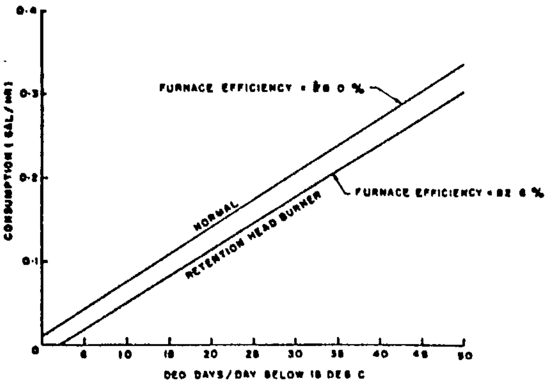

Fig. 8 The effect of improved burner performance: retention-head burner, Home C

Limitations to this technique are imposed by the maximum heat requirement of the home since reductions in firing rate must reduce the output capacity of the furnace. Furnace sizing during installation is usually generous, as the operating times shown in Fig. 6 illustrate.

The furnace in Home B operates continuously at external temperatures below −24°C and reductions in nozzle size could lead to uncomfortably low internal temperatures. The furnace in Homes C, D, and E have all passed their 50 percent operating time at external temperatures of −40°C and could accommodate marginally lower firing rates. The furnace in Home A had not reached its 50 percent operating time at an external temperature of −50°C and this was the home used for the data presented in Fig. 5.

The Effect of a Positive Chimney Damper. To establish the effect of a positive chimney damper on fuel consumption, prototype dampers were constructed to laboratory specifications and installed after the barometric damper in the flue pipes of selected homes. The clearance on these dampers was small (1.6 mm). A safety interlock was added to the burner power circuit to ensure that the burner could not ignite whilst the damper was in a closed or partially-closed position. The spring-loaded damper returned to its fully-closed position 30 s after the end of the burner operating cycle.

These dampers have operated over two winter test periods and have not experienced any mechanical failures when installed in rigid flue pipes; deformation of the flue pipes can lead to the damper locking in a partially closed position. When these dampers are in use it has been found essential to maintain a high standard of burner shut-down performance by the use of a solenoid valve to avoid odors from the combustion of oil-dribble from the atomising nozzle.

Where chimney dampers were installed, fuel savings of between 5 and 10 percent were achieved. The extent of these savings is a function of external temperature and may also be related to the type of heating system since the highest savings were recorded in a home heated by hot water where a continuous chimney loss by convection from relatively high-temperature surfaces (60°C, 140°F) existed.

The Effect of Improved Burner Performance

The effect of upgrading the burner performance was investigated using different burners in two homes. The first burner, installed in Home E, was a prototype blue-flame burner developed at the Canadain Canadian Combustion Research Laboratory [1][1] and capable of smoke-free operation at an excess-air level of 25 percent when used as a retrofit burner in an existing furnace. The second burner, installed in Home C, was a commercial, flame retention-head burner known to be capable of performance comparable to that of the blue-flame prototype.

The results from these two homes are shown in Figs. 7 and 8. In both homes a reduction in fuel consumption was recorded which was of constant magnitude; when expressed as a percentage of fuel used this saving decreased with decreasing external temperature. Although the saving from the prototype blue-flame burner was smaller than that from the commercial retention-head burner, the result was considered satisfactory to the blue-flame development program since it was intended that this burner should be used with an optimized combustion chamber whilst preserving a physical retrofit capability.

Comparison of Fuel Conservation Techniques

In order to provide a simple comparison of the merits of the various fuel conservation techniques investigated in the course of the experimental program, the linear equations relating fuel consumption in Imperial gph to degree days below 18°C have been integrated over a simulated winter of 4260 Celsius degree days with a mean winter temperature of −2°C. The results are presented in Table 2.

The absolute magnitude of the saving from any fuel conservation technique must depend on the normal fuel consumption. When the percentage saving figures listed in Table 2 are compared, the order of effectiveness in Table 3 emerges.

Plainly, the most cost-effective technique is severe thermostat cutback. In view of the magnitude of the normal fuel consumptions recorded in these experiments and current trends in the price of home heating oil, all of these techniques can be regarded as offering significant dollar advantages to the home owner within three years.

Table 2 A comparison of the fuel conservation techniques over a typical winter (4260 degree days below 18°C

Conservation Technique	Fuel Consumption : Imperial Gallons				
	HOME A	HOME B	HOME C	HOME D	HOME E
None	789.0	1181.5	716.4	881.6	953.7
Thermostat Cut Back					
Slight			717.0		912.1
Moderate	716.2			800.1	887.0
Severe		1171.7			
Improved Burner Performance			578.2		818.8
Positive Chimney Damper			658.8	798.7	
Reduced Firing Rate	715.5				

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[1] Numbers in brackets designate References at end of paper.

Table 3 The relative effectiveness of various fuel conservation techniques

Conservation Technique	% Fuel Saving	Approximate Cost
High Efficiency Burner	14 – 20	$100
Severe Thermostat Cut-back	15.2	$ 0
Reduced Nozzle Size Moderate Thermostat Cut-back	7 – 10	$ 10 $ 0
Positive Chimney Damper	0 – 10	$ 60 (est.)
Slight Thermostat Cut-back	0 – 2	$ 0

Conclusions

A simple evaluation procedure has been developed which enables a precise field assessment of fuel conservation techniques to be made.

Several fuel conservation techniques have been assessed using this procedure and placed in the following order of effectiveness:

1 Improved burner performance;
2 severe overnight thermostat cutback;
3 reduced firing rate;
moderate thermostat cutback;
4 positive chimney damper;
5 slight thermostat cutback.

Acknowledgments

In a field study of residential heating the willing co-operation of the homeowners is invaluable. The authors wish to acknowledge the patient daily recording of data made by Mr. and Mrs. E. R. Mitchell, Mr. and Mrs. B. C. Post, Mr. and Mrs. G. K. Lee, Mr. and Mrs. F. D. Friedrich and Mrs. T. D. Brown. In addition, the continuing discussion of the test data with colleagues at the Canadian Combustion Research Laboratory has contributed greatly to the content of this paper.

References

1 Mitchell, E. R., Brown, T. D., and Post, B. C., "Oil Burner Assembly," Canadian Patent Application 230, 344.

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APPENDIX B

PROPERTIES OF METHANOL

Ultimate Analysis, lb/lb

Carbon	(C)	0.375
Hydrogen	(H)	0.126
Oxygen	(O)	0.499
	TOTAL	1.000

Calorific Value (HHV),	Btu/lb	9,776
	Btu/gal (Imp)	78,012
Specific Gravity		0.798
Flash Point, °C		11
Flammability Limites, % vol		6.7 to 36.0

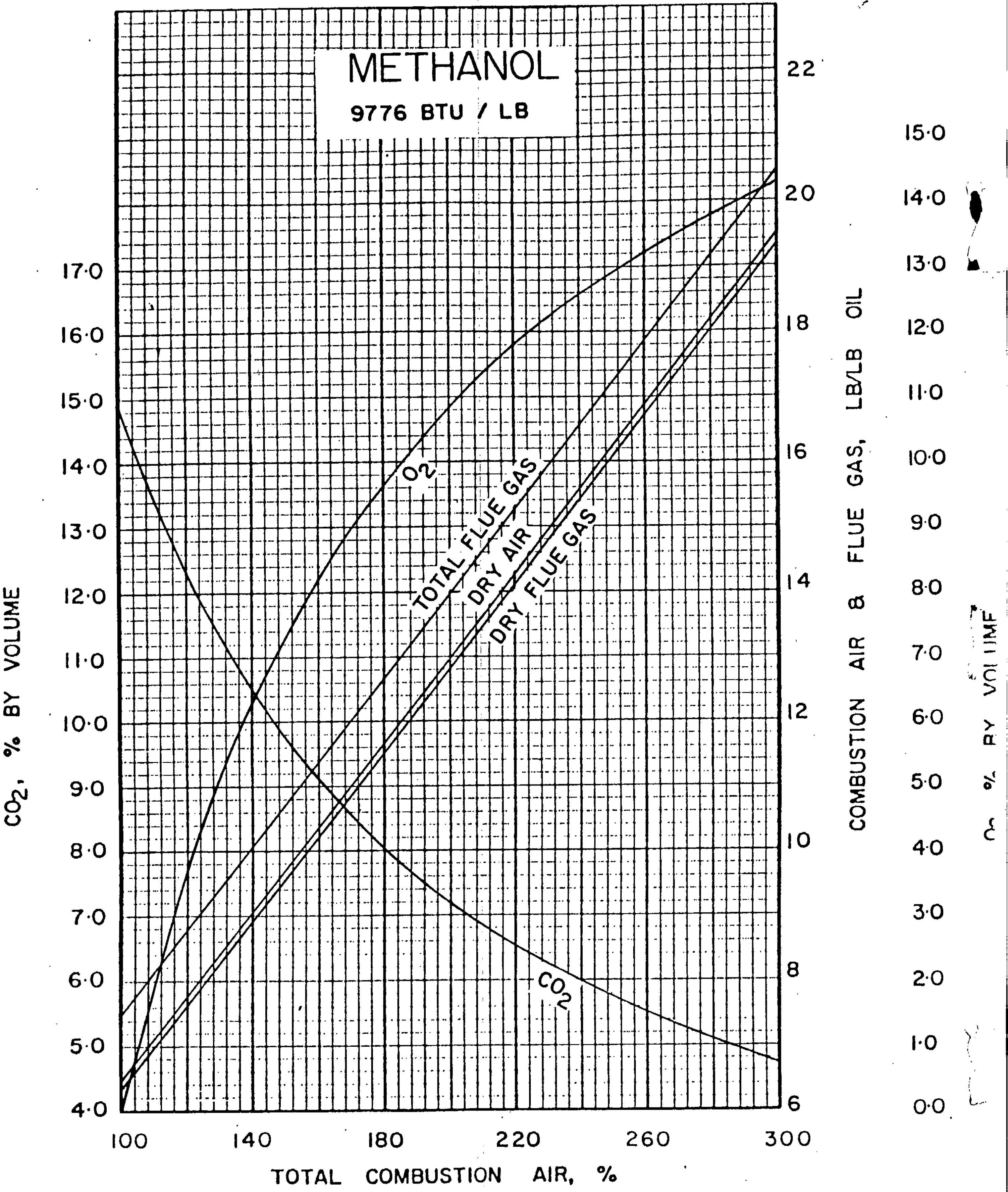

FIGURE 1· COMBUSTION DATA, WEIGHT BASIS

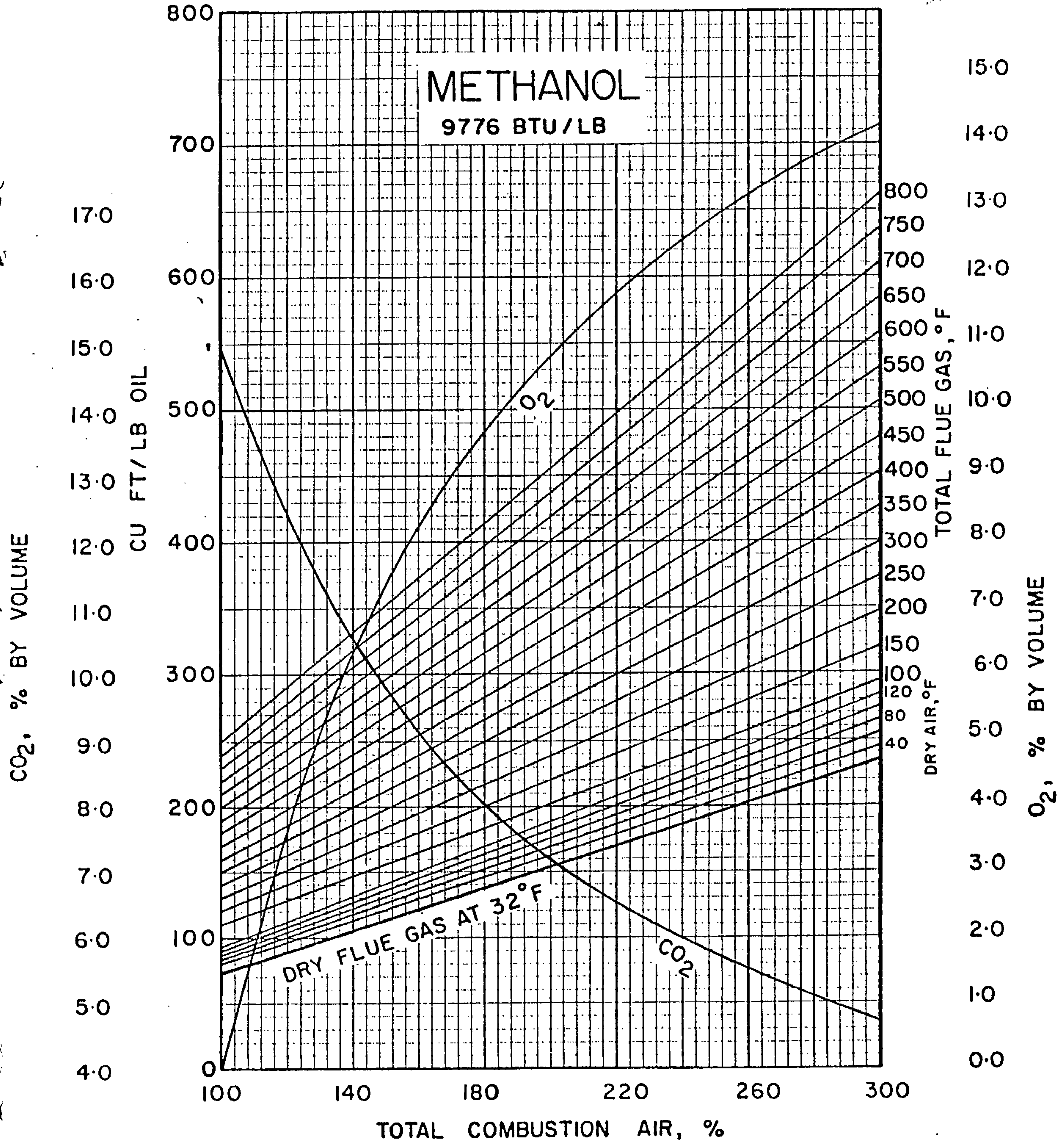

FIGURE 2. COMBUSTION DATA, VOLUME BASIS.

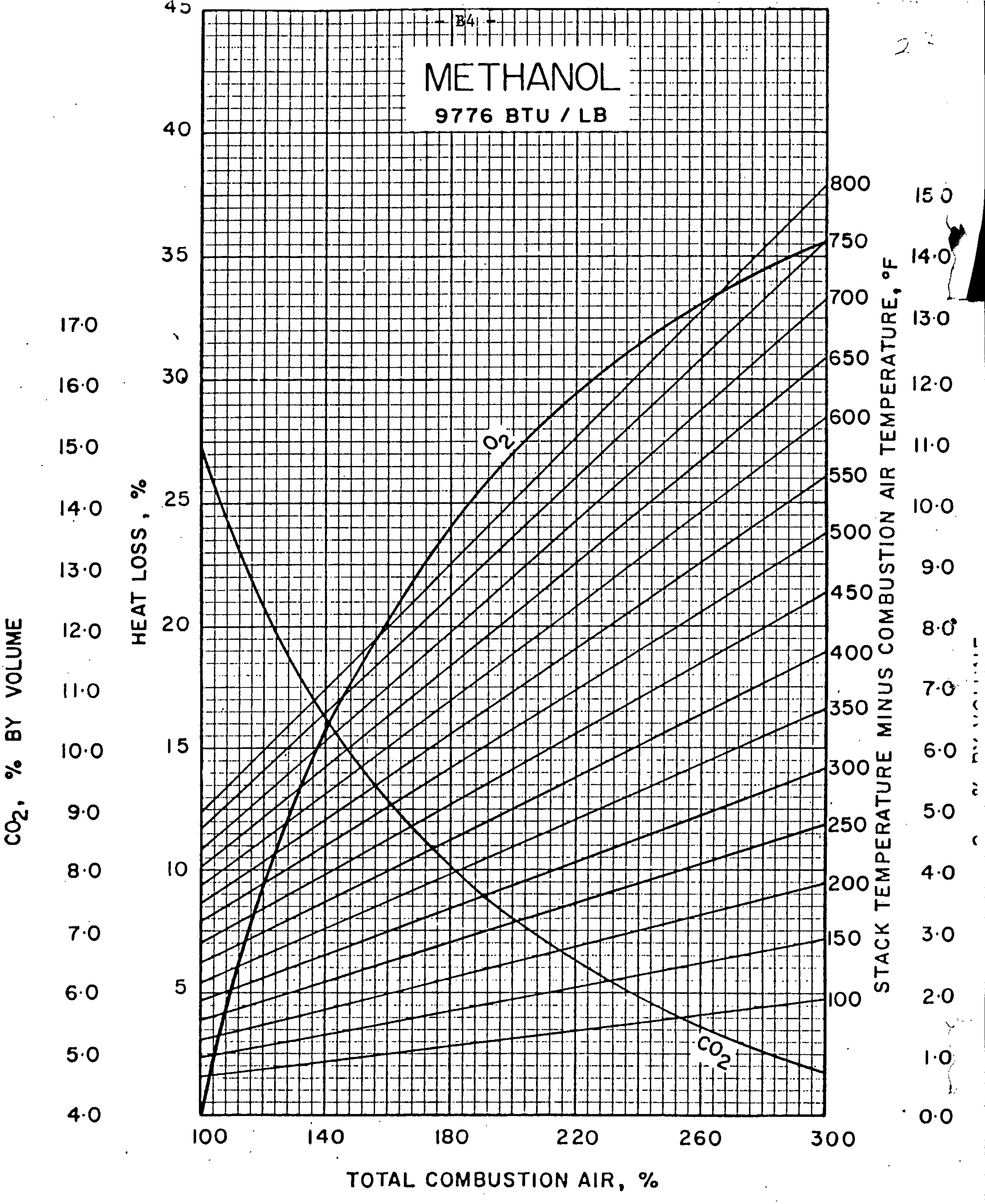

FIGURE 3· DRY FLUE GAS LOSS FOR A RANGE OF TEMPERATURE DIFFERENTIALS·

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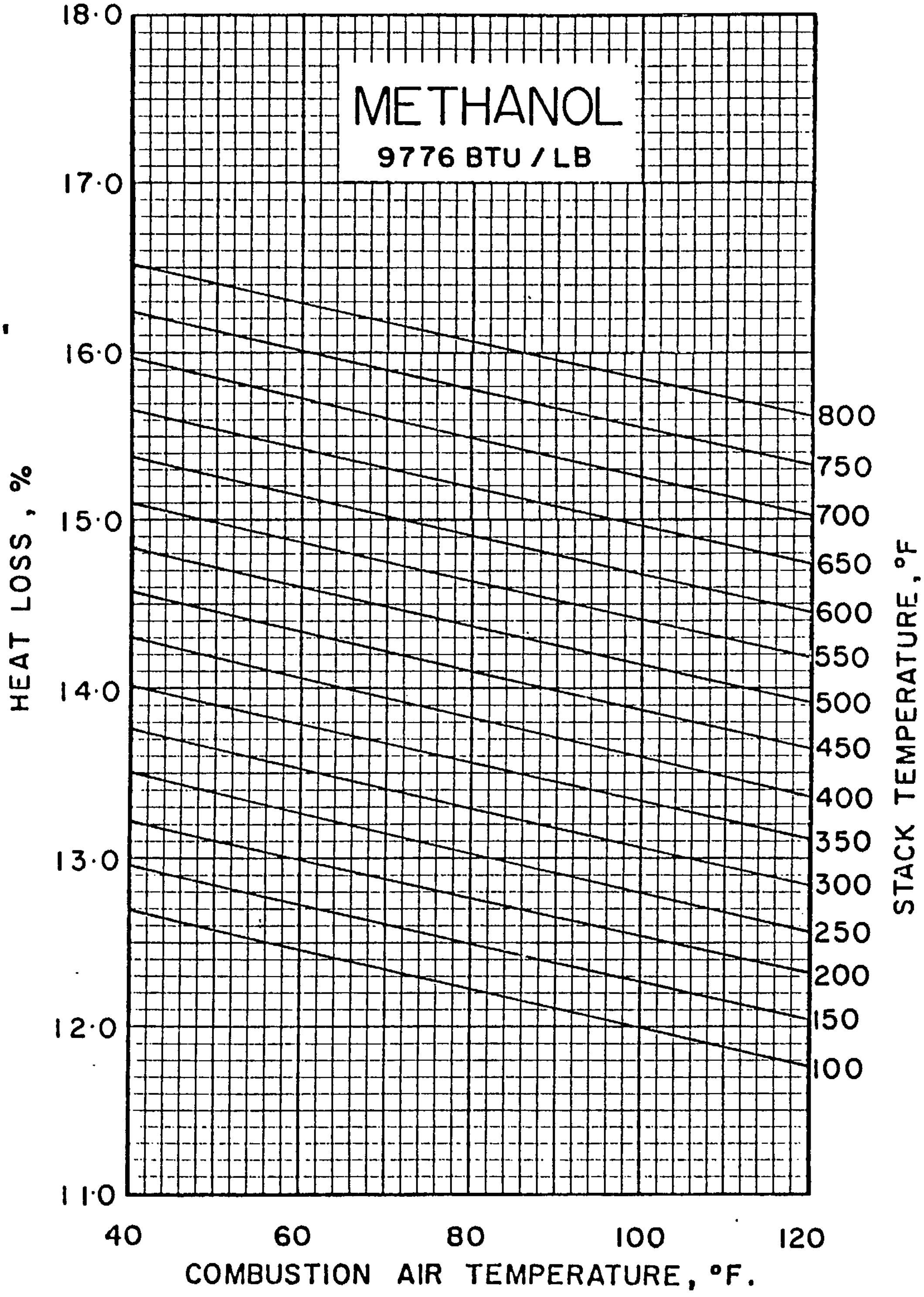

FIGURE 4. HYDROGEN LOSS FOR A RANGE OF STACK TEMPERATURES.

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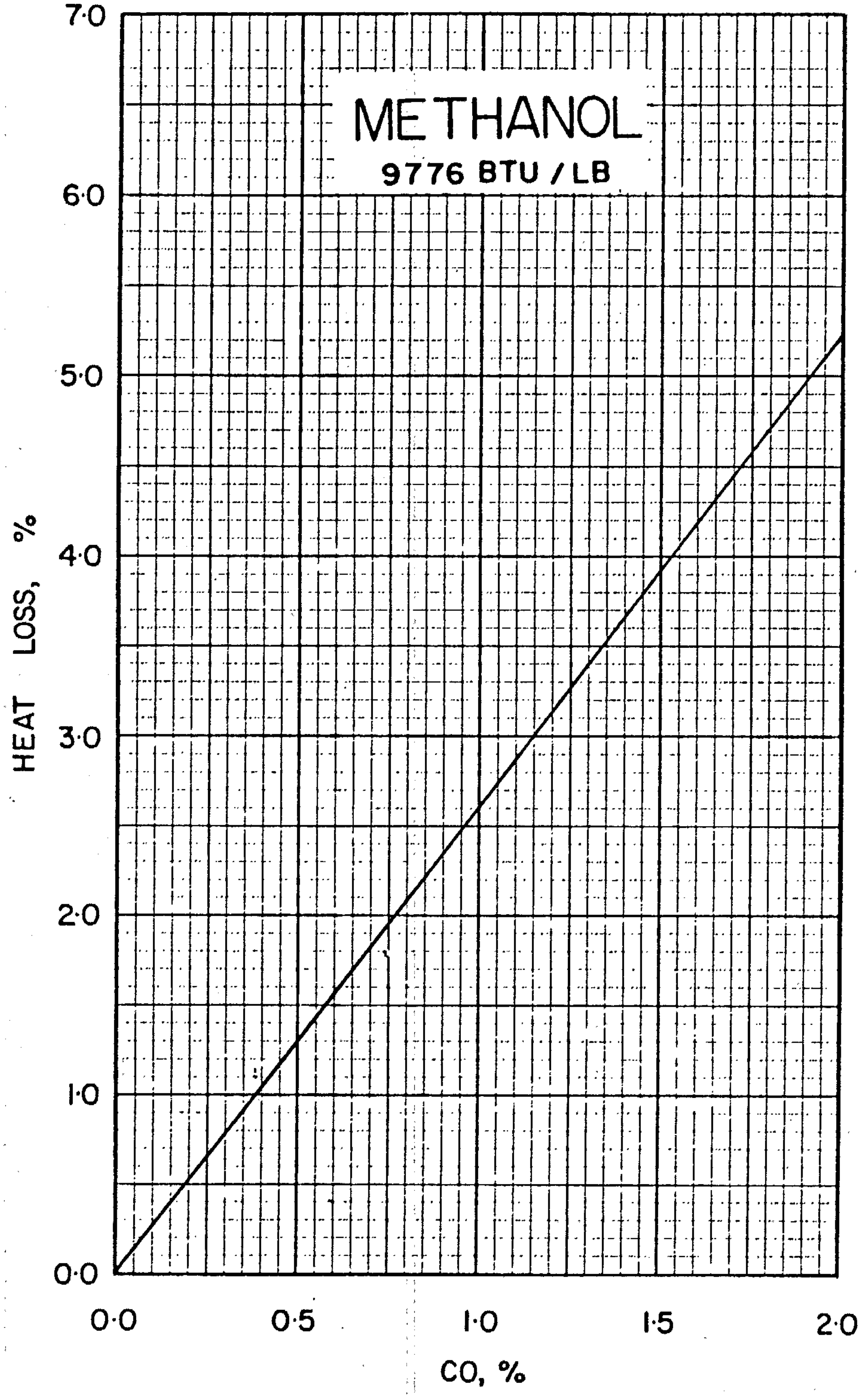


FIGURE 5· HEAT LOSS FOR A RANGE OF CO CONCENTRATIONS, ASSUMING NEGLIGIBLE EXCESS AIR

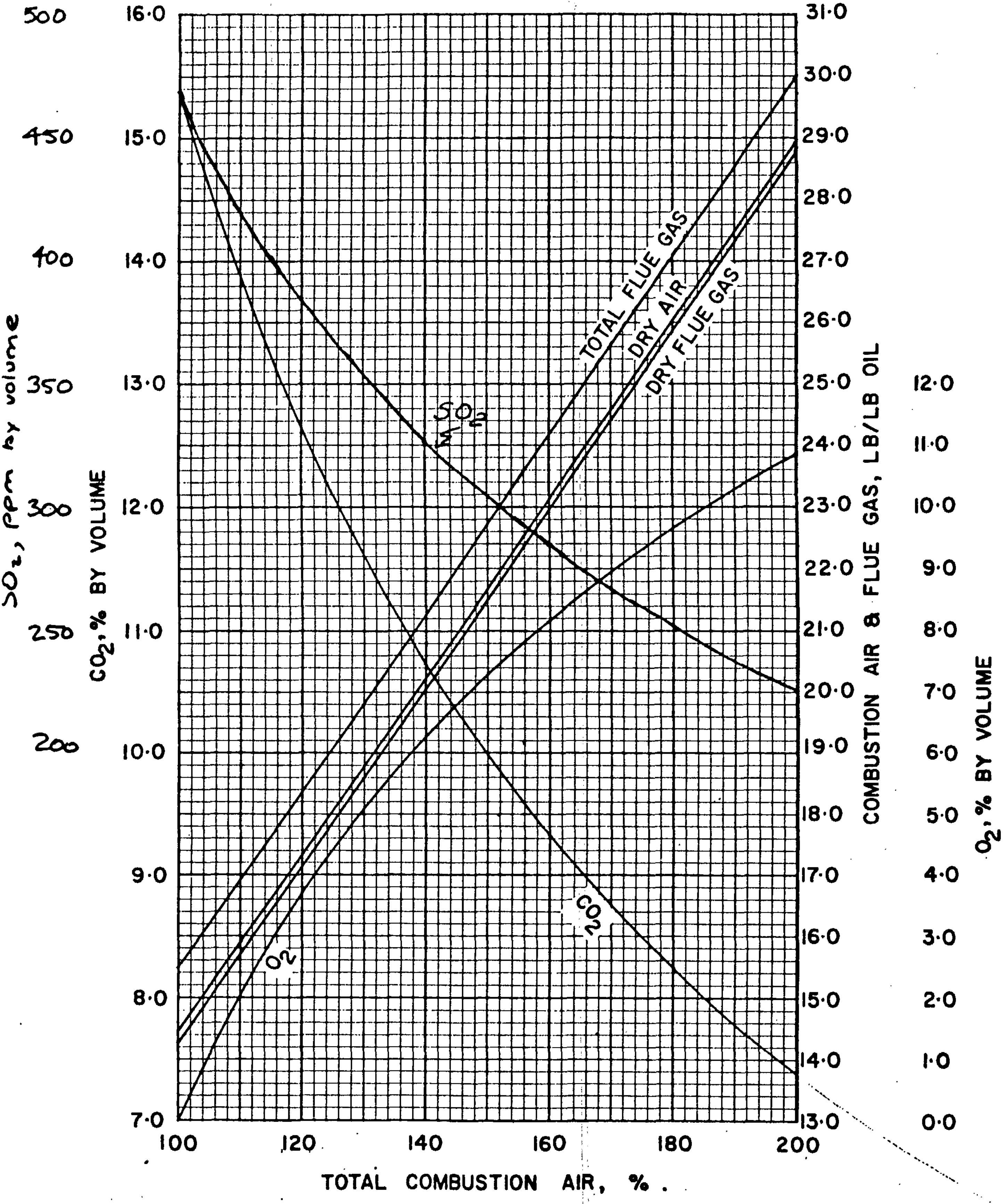
APPENDIX C

PROPERTIES OF NUMBER 2 FUEL OIL

Ultimate Analysis, lb/lb

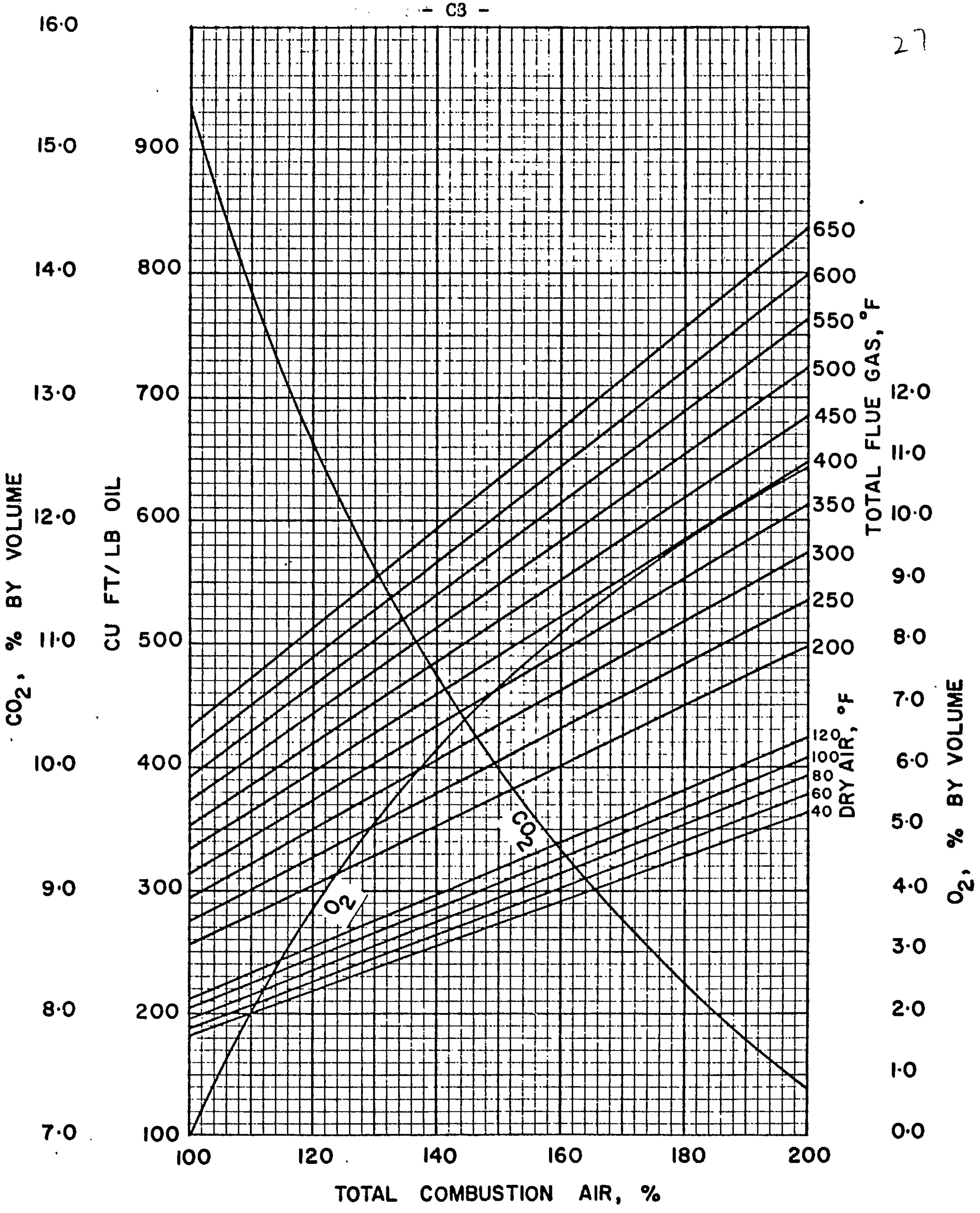
Carbon	(C)	0.860
Hydrogen	(H_2)	0.133
Sulphur	(S)	0.007
Nitrogen	(N_2)	-
Oxygen	(O_2)	-
Ash		-
Moisture		-
	TOTAL	1.000

Calorific Value, Btu/lb	19,590
Btu/gal (Imp)	166,000
Specific Gravity	0.850
Flash Point, °C	50
Flammability Limits, % vol	0.7 to 6.0

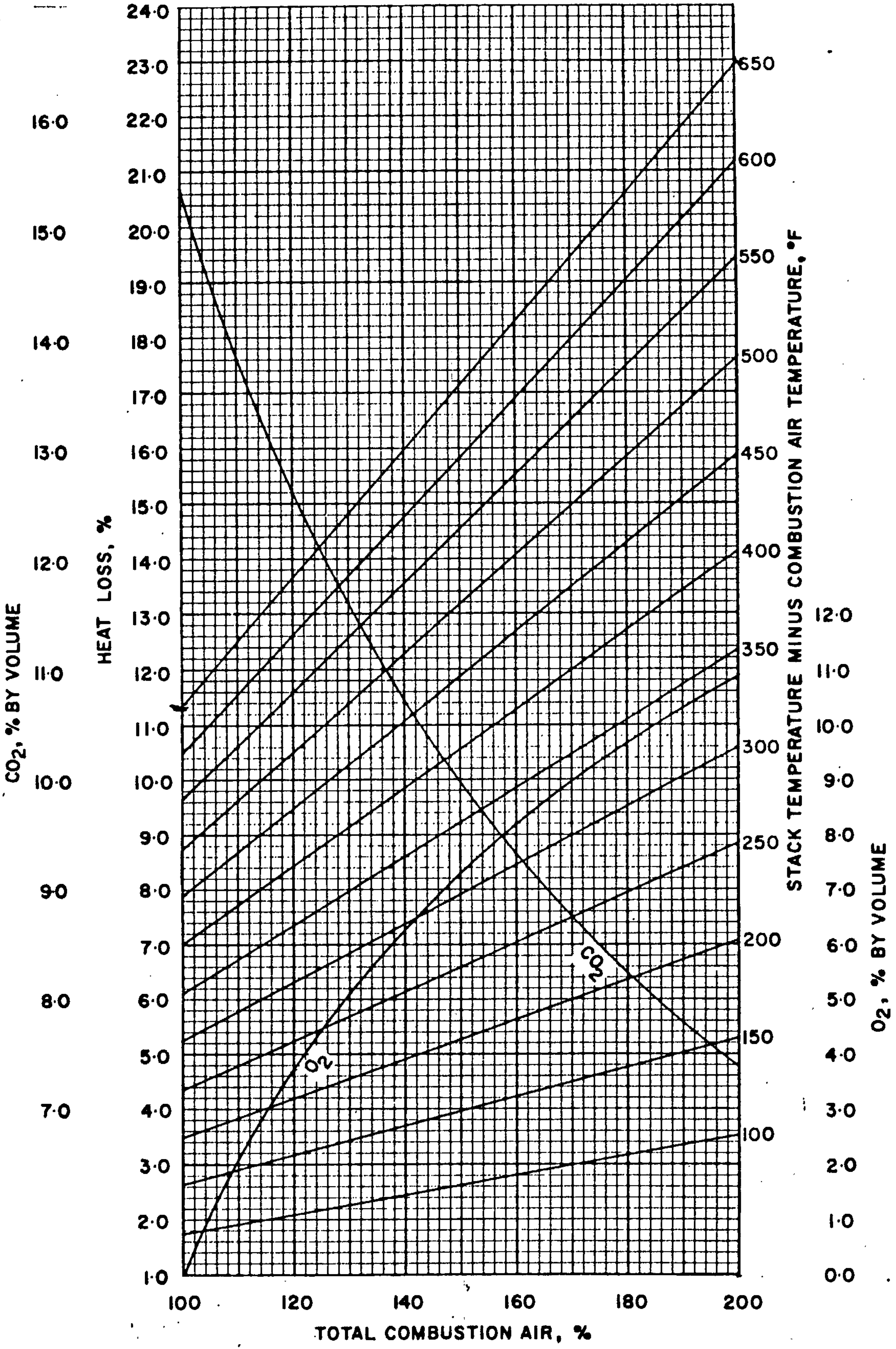


APPENDIX C - FIGURE 1· COMBUSTION DATA, WEIGHT BASIS.
(NO· 2 FUEL OIL)

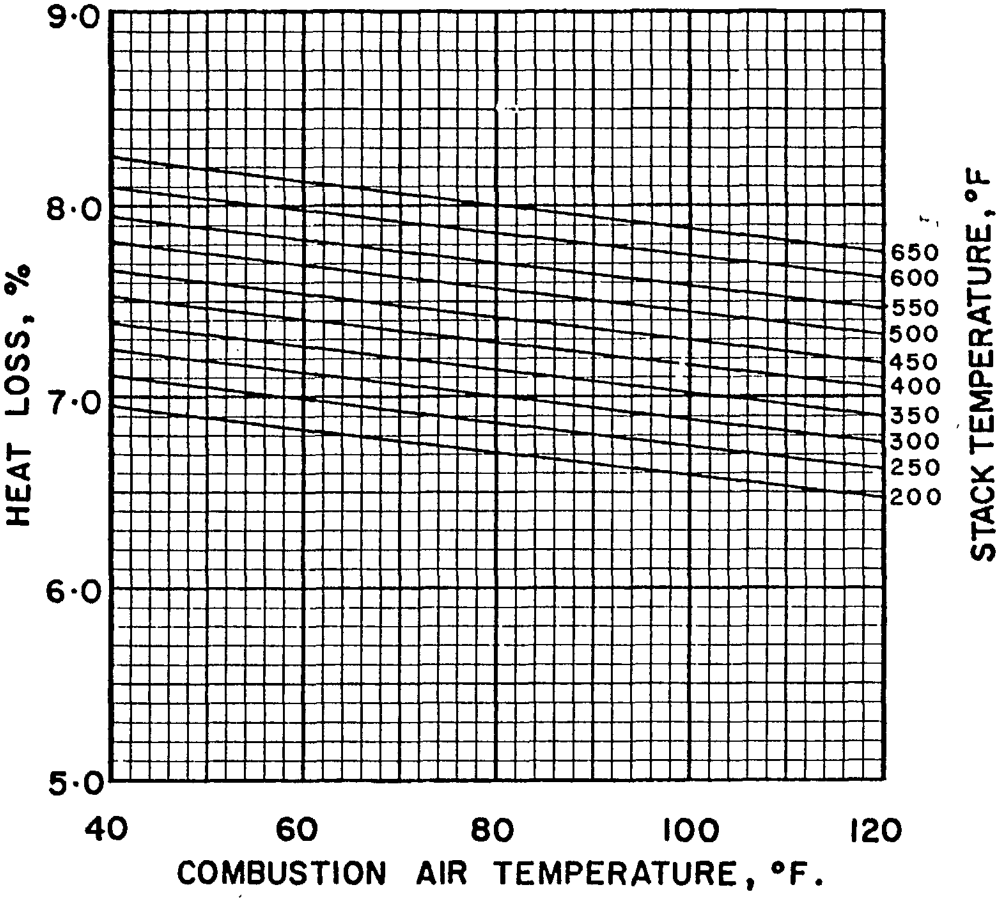
27



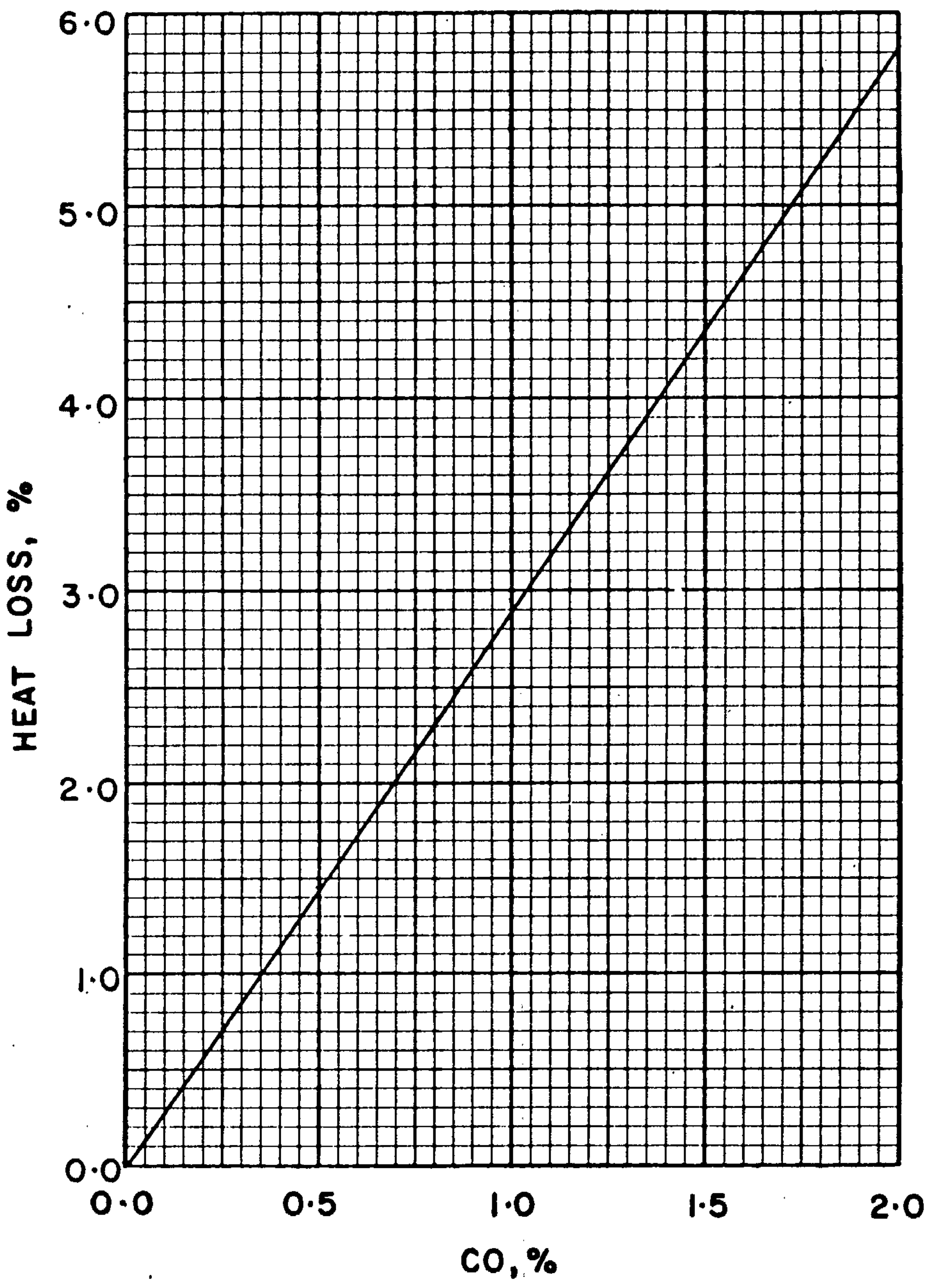
APPENDIX C - FIGURE 2. COMBUSTION DATA, VOLUME BASIS. (NO. 2 FUEL OIL)



APPENDIX C – FIGURE 3· DRY FLUE GAS LOSS FOR A RANGE OF TEMPERATURE DIFFERENTIALS. (NO· 2 FUEL OIL)



APPENDIX C-FIGURE 4. HYDROGEN LOSS FOR A RANGE OF STACK TEMPERATURES. (NO. 2 FUEL OIL)



APPENDIX C - FIGURE 5. HEAT LOSS FOR A RANGE OF CO CONCENTRATIONS, ASSUMING NEGLIGIBLE EXCESS AIR. (NO. 2 FUEL OIL)

APPENDIX D

PROPERTIES OF NATURAL GAS

FUEL 1007 NATURAL GAS

Analysis, mole %

Methane	(CH_4)	91.57
Ethane	(C_2H_6)	5.01
Propane	(C_3H_8)	0.25
N-butane	(C_4H_{10})	Trace
Iso-butane	(C_4H_{10})	0.01
N-pentane	(C_5H_{12})	Trace
Iso-pentane	(C_5H_{12})	Trace
Hexanes plus	($C_6H_{14}+$)	Nil
Nitrogen	(N_2)	2.65
Carbon dioxide	(CO_2)	0.49
Oxygen	(O_2)	Nil
Hydrogen	(H_2)	Nil
	TOTAL	100.00

Total sulphur (including 0.12 gr/100 cu ft at odorant)
= 0.23 gr/100 cu ft.

Note: The following data apply under standard conditions of 60°F and 29.92 in. Hg.

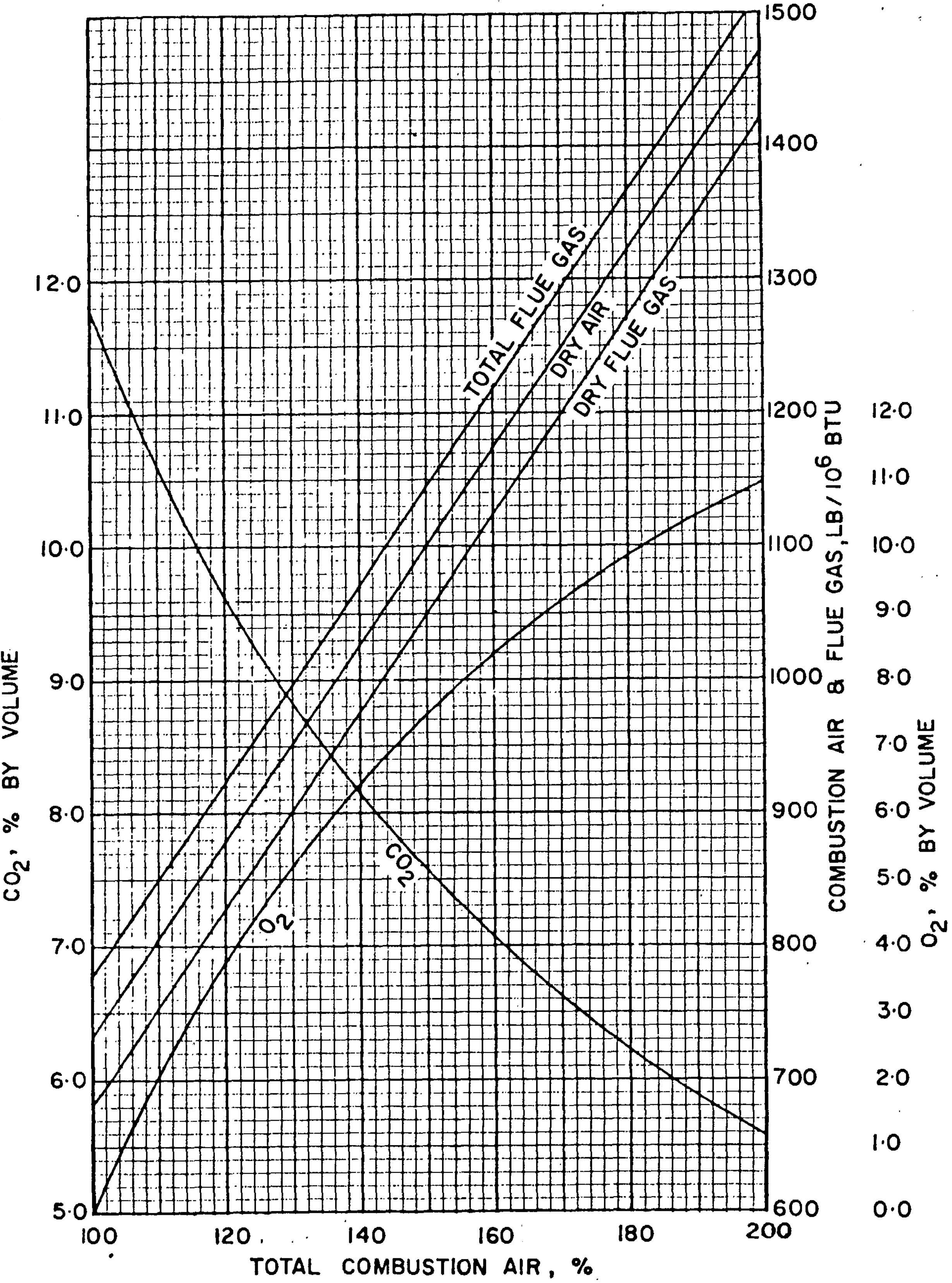
Specific gravity relative to air:	0.598
Specific weight, lb/cu ft:	0.0456
Specific volume, cu ft/lb:	21.93

Calorific Value

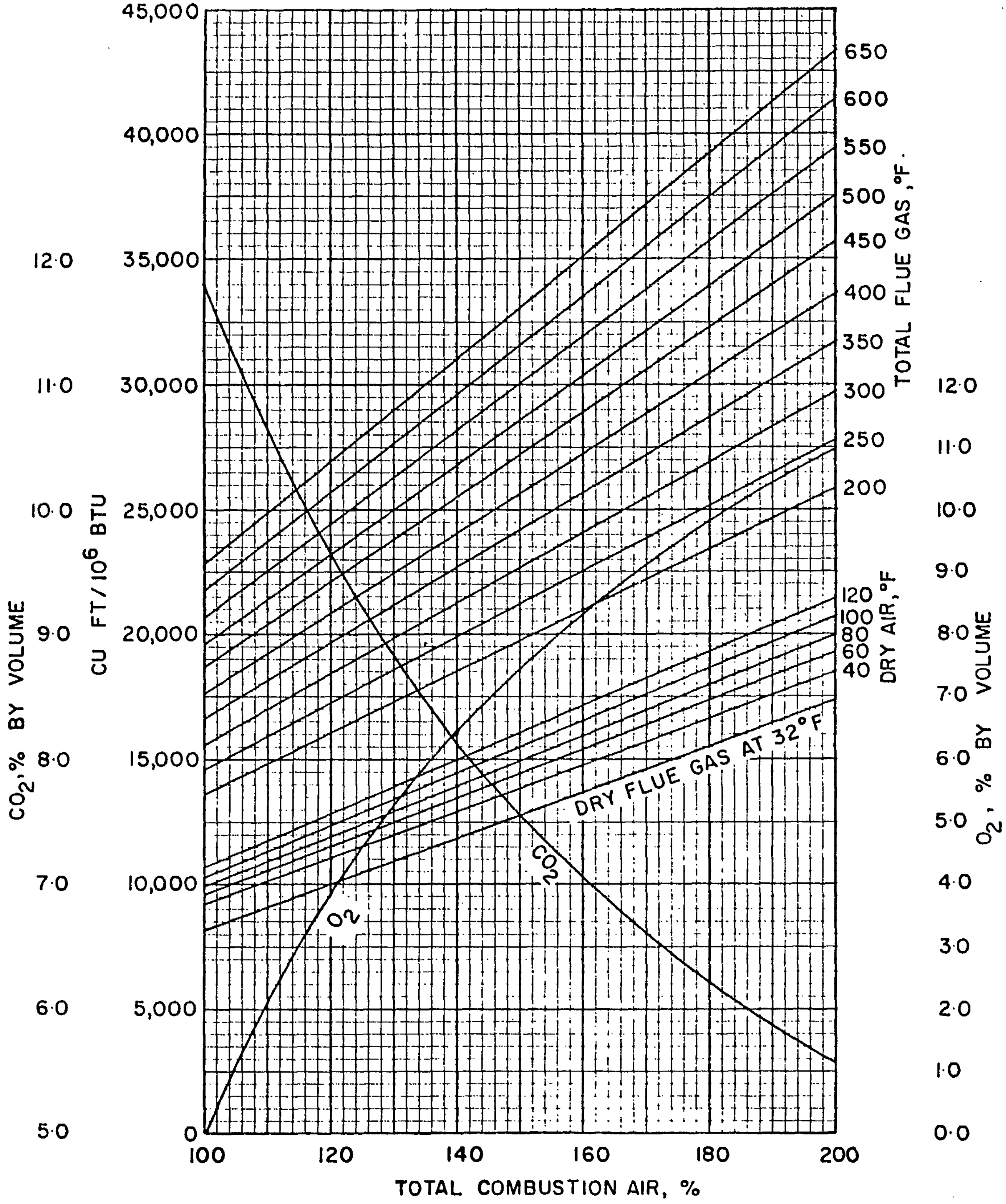
Btu/cu ft of gas:	1007
Btu/lb of gas:	22,080

Conversion Factors

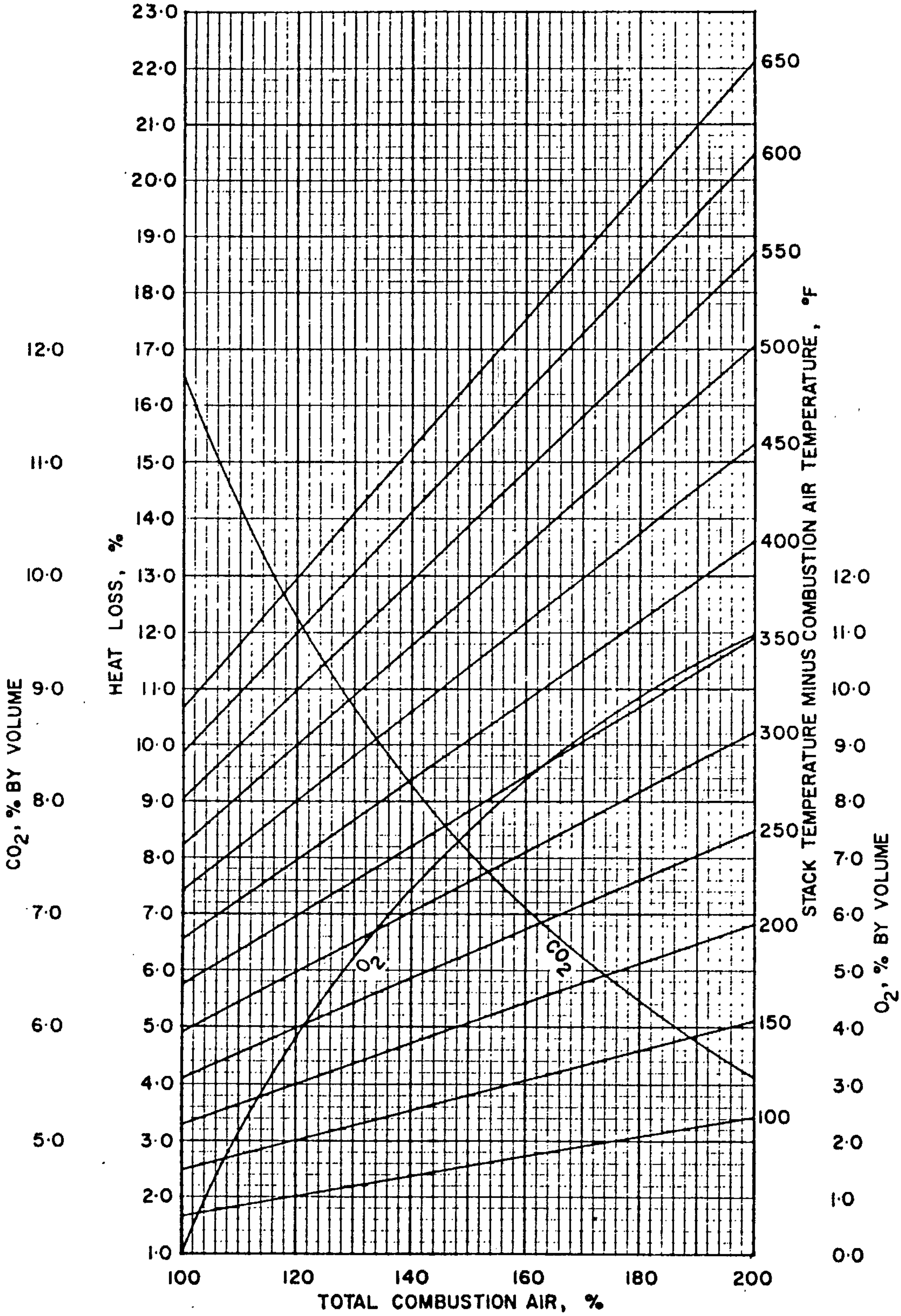
10^6 Btu = 993.0 cu ft of gas
10^6 Btu = 45.28 lb of gas



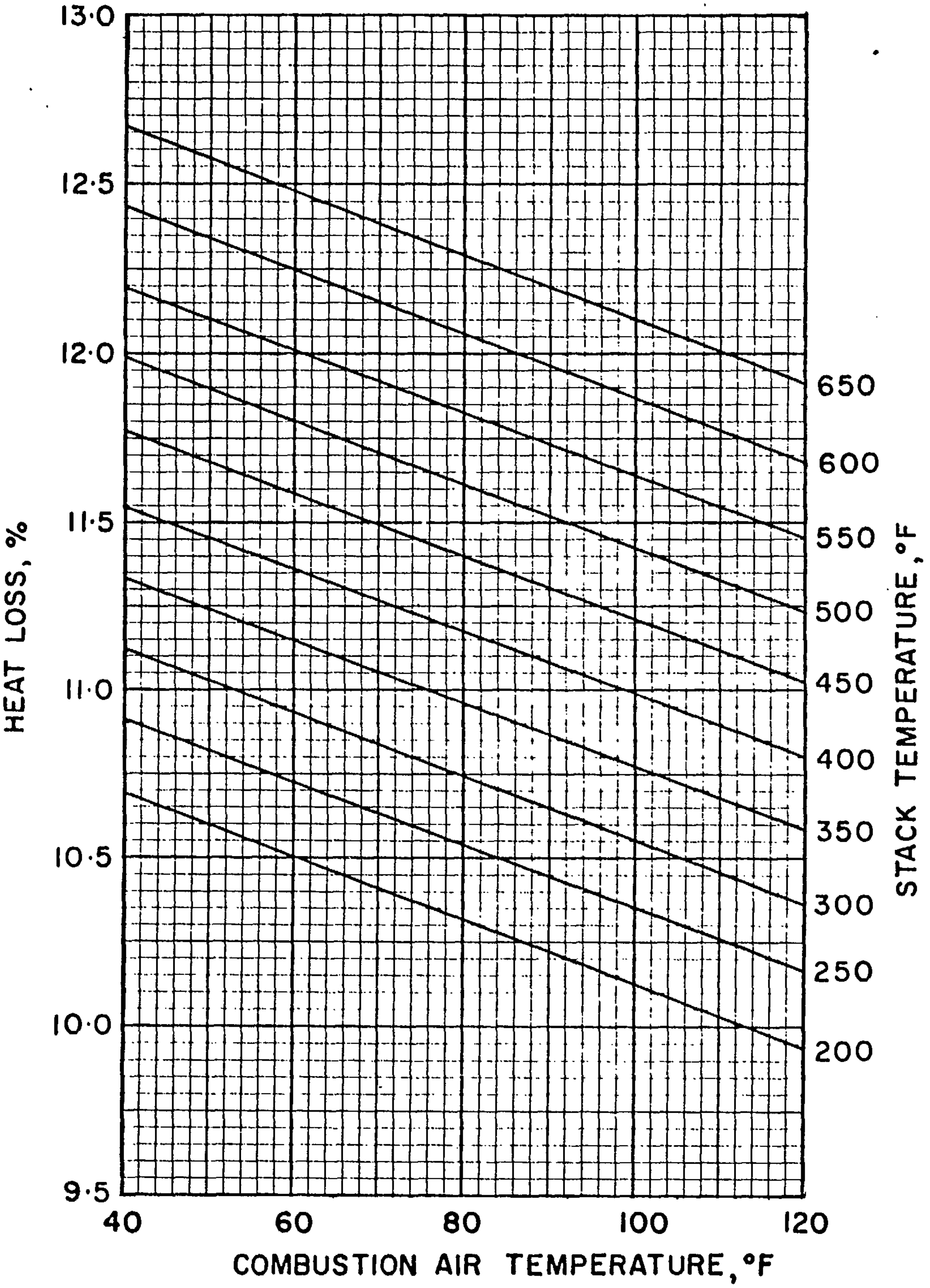
APPENDIX D - FIGURE 1: COMBUSTION DATA, WEIGHT BASIS.
FUEL: NATURAL GAS, 1007 BTU / CU FT.



APPENDIX D - FIGURE 2: COMBUSTION DATA, VOLUME BASIS.
FUEL: NATURAL GAS, 1007 BTU/CU FT.



APPENDIX D -FIGURE 3 DRY FLUE GAS LOSS FOR A RANGE OF TEMPERATURE DIFFERENTIALS
FUEL: NATURAL GAS, 1007 BTU / CU FT



APPENDIX D- FIGURE 4: HYDROGEN LOSS FOR A RANGE OF STACK TEMPERATURES.
FUEL: NATURAL GAS, 1007 BTU/CU FT.

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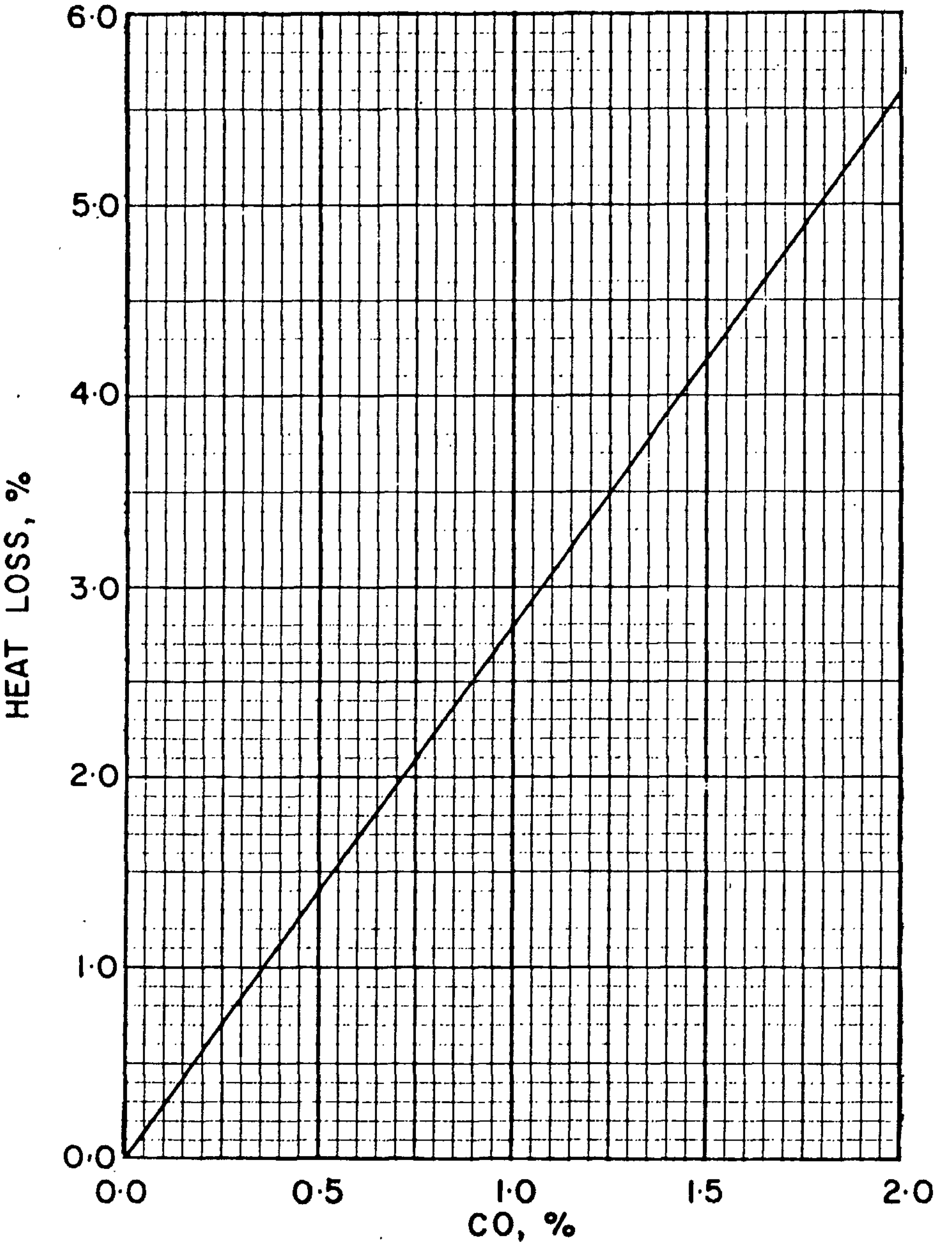

APPENDIX D
FIGURE 5· HEAT LOSS FOR A RANGE OF CO CONCENTRATIONS, ASSUMING NEGLIGIBLE EXCESS AIR.
FUEL: NATURAL GAS, 1007 BTU / CU FT