COMBUSTION OF WINTER RAPE PRODUCTS IN A RESIDENTIAL STOVE

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ABSTRACT

The characteristics of winter rapeseed have been investigated to determine its potential as a fuel in residential stoves. The study included the plant residue and the seed meal which remains after removal of the oil with a mechanical press. Dwarf Essex, a variety grown for industrial applications, was pelleted for use in combustion tests. A commercially produced residential pellet stove was used to determine the emissions characteristics and the long term effects of the direct combustion of winter rape products.

INTRODUCTION

Rape plant residue and rapeseed meal are currently unusable by-products of rape oil extraction. Residue includes all portions of the plant except the seed. Residue is usually left in the field when the seed is harvested. The oil pressed from the seeds is being tested as an alternative fuel in diesel engines. The meals left by the pressing process from some rapeseed varieties have a high glucosinolate content which make them unsuitable as animal feed (Mahler et al., 1986). The search for a use for these by-products led to the consideration of rape products as fuels in direct combustion processes.

Use of the by-products of the rape oil process for energy sources also provides opportunity for rape to be used as an energy crop. Total energy crops are good candidates for use with subsidies such as the set-aside program because they do not compete with existing products.

Recent developments in the home heating industry enhance the prospect for the use of non-conventional fuels such as rape products. The introduction of pellet burning stoves gives additional control over combustion processes and therefore allows the burning of materials with characteristics considerably different than those of wood or coal. A variety of configurations increases the likelihood of finding a combustion device with characteristics compatible with the unique properties of rape products.

LITERATURE REVIEW

Many residue materials have been evaluated as potential fuels. A few examples include: the investigation of corn-cob combustion by Payne et al. (1984), Morey (1984) and others; evaluation of fruit pomace by Mason et al. (1985); and studies of fuel characteristics of evergreen shrubs by Erdman et al. (1984). Information specific to the combustion of rape residue and rapeseed meal could not be found.

The properties of rape residue have seldom been investigated because it is usually not collected when the seed is harvested. Information generally applicable to vegetable crop residues (Envirosphere, 1980) indicates that a gross heat of combustion of 17.5 kJ/g (7520 Btu/lb) can be expected.

A number of the properties of rape meal have been determined. Katz (1982) reported a heat content of 22.5 kJ/g (9670 Btu/lb). This is very comparable to the commonly reported value of 20 kJ/g (8600 Btu/lb) for wood, but similarities end there. Wood is often treated as a three component mixture of cellulose, hemicellulose, and lignin in a 50:25:25 ratio. All three of these components are included in the fraction termed crude fiber in food technology. Sosulski et al. (1969) reported a value of 14.0% (oil-free, dry basis) for the crude fiber content of rape meal of the Argentine variety and an ash content of 8.0%. This is more than three times the 2.5% ash content of hardwoods reported by Junge (1975). The major portion of rape meal is protein (45.5%) and nitrogen free extract (32.5%) as reported by Sosulski. These components are virtually absent from most woods.

The differences between rape meal and wood emphasizes the importance of selecting a combustion device compatible with the properties of the meal. Edwards (1974) discusses the possible configurations of fuel and air supplies in combustion chambers. Air supply is usually separated into primary, for oxidizing solid fuel; and secondary, for completing oxidation of gaseous products. Continuous fuel feed mechanisms are either overfeed or underfeed devices. The "over" and "under" describe the location of the fuel inlet with respect to the burning pile. These two configurations provide completely different environments for fuel oxidation.

The overfeed arrangement (fig. 1) places fresh fuel on top of the burning pile. Evaporation of fuel moisture and release of volatiles absorb heat from the radiation of gases combusting over the pile. As the nonvolatile portion of the fuel settles into the pile, it is oxidized by the primary air which is introduced below the pile.

In the underfeed arrangement (fig. 2), fresh fuel is introduced below the fuel pile. Heat for pre-combustion processes such as volatilization must be conducted downward from the burning pile. When fresh fuel is augured into the chamber, it pushes the nonvolatile portion

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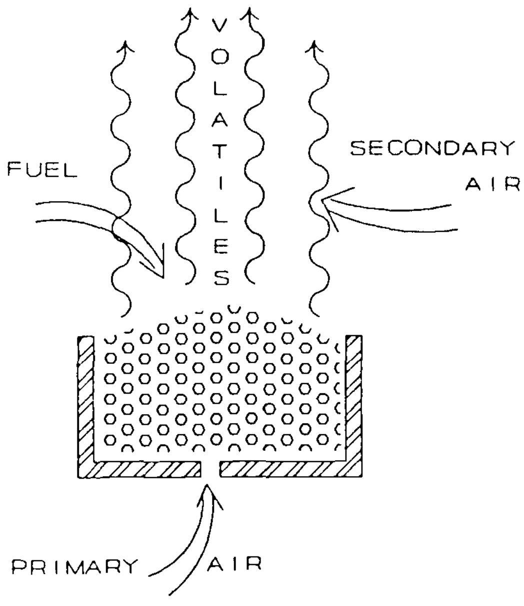

Figure 1–Overfeed configuration.

of the fuel upward into the primary air supply and oxidation begins.

The difference in the environments provided by the two fuel feed configurations has several implications. Most important is the temperature at which initial fuel heating occurs. Shafizadeh and Chin (1977) list 500 to 773 K (900 to 1400 R) as the range of temperatures at which the components of wood undergo pyrolysis. Pyrolysis contributes to burning by breaking down the fuel, but the conditions under which it occurs have significant consequences. A study by Batelle-Columbus Laboratories (Cooke et al.,1981) listed premature pyrolysis and excessive pyrolysis rate as the first factors affecting emissions. Thus, control of pyrolysis conditions is necessary for control of pollutants.

It is obvious that fuel which is introduced between a burning pile and radiating gases will experience higher temperatures than those existing under the pile. Edwards (1974) concludes that "...underfeed is conducive to promoting the oxidation of the volatile organics rather than pyrolysis as occurs when fresh fuel is introduced on top of the bed". The composition of rape meal suggests that the underfeed configuration will be essential for proper combustion.

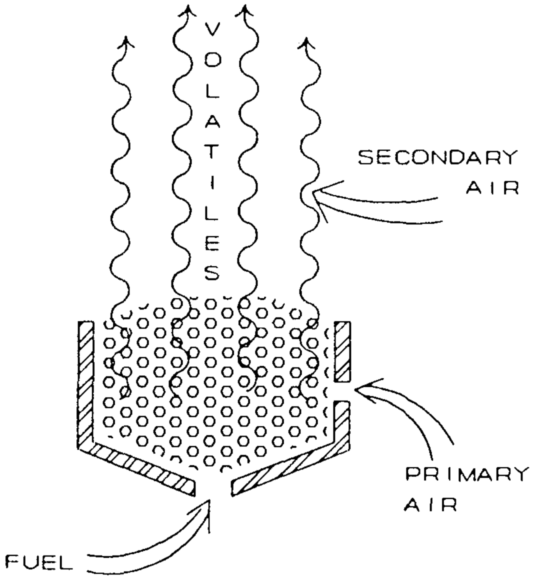

Figure 2–Underfeed configuration.

Another major factor in the relationship between pyrolysis and oxidation is the amount of available oxygen. The concentration of oxygen is quantified by the excess air (EA). Excess air is the portion of air introduced into the combustion chamber that is not necessary for stoichiometric oxidation of the fuel. It is obvious that EA enhances the combustion efficiency (portion of fuel completely oxidized), but EA will decrease the heat output of the appliance because heated EA is exhausted. Breene (1976) studied coal-fired burners and concluded "Impressive fuel savings can be achieved by minimizing excess air usage...". In some circumstances, lower EA can have lower emissions because of decreased particulate entrainment.

Emissions from residential woodstoves now exceed the particulate emissions from industry in some areas. This information was revealed by a study done for the formulation of the Oregon State Implementation Plan, and resulted in the inception of a woodstove certification program which requires determination of particulate emissions of all models of stoves sold in that state (Oregon Department of Environmental Quality, 1984). Standards similar to those of Oregon have been enacted on the national level (Office of the Federal Register, 1988). States may enact more stringent standards if necessary. State Implementation Plans (SIP) are required by the 1977 amendments to the U.S. Government Clean Air Act of 1970 (Office of the Federal Register, 1988b). Mors et al. (1981) says "...states with woodburning air pollution problems may attempt to control stoves through their SIP" as has Oregon. Whatever the means of implementation, evaluation of a fuel must include consideration of environmental impact and potential regulation.

OBJECTIVES

It is the intent of this study to evaluate the suitability of pelleted rape residue and rape meal as fuels in residential stoves. Specific objectives are:

1. Determine the fuel characteristics of rape including:
   a. Physical parameters of density, moisture content, and heat content.
   b. Composition including ash content and elemental analysis.
   c. Combustion characteristics including efficiency and deposit formation.
   d. Particulate emissions.
2. Compare the performance of pelletized and unpelletized rape meal as fuel with that of a commercial wood pellet.
3. Determine the practical problems associated with burning rape pellets through 100 hour continuous operation in a commercial pellet burning stove.
4. Compare the cost of burning pelleted rape meal or rape residue with that of commercially available wood pellets for residential use.

METHODS AND MATERIALS

PELLETING

The original forms of the plant residue and of the meal are not suitable for combustion in conventional stoves. The plant material is objectionably bulky and densification is desirable. Rape meal cannot be handled in its original form without breakage and trials showed that complete combustion of the resulting material was unlikely. These results led to the investigation of pelleting.

The rape plant residue pelleted well in a commercial mill but rape meal created several problems. The first rape meal pellets used in this study were produced by an agricultural pelleting facility. These rape pellets were noticeably softer than the commercially available pellets made from densified waste wood (soft wood) products – sawdust, bark, hog fuel, trash wood (Lignetics, 1988) and produced higher and less controllable burn rates at the same volume feed rate. Therefore, several forms of mixed fuel pellets were also tested. Pellets made of a blend of 60% rape meal and 40% red fir shavings produced excellent pellets in a commercial mill. These pellets will be referred to as BLEND for the remainder of this paper. The term MIX will be used to describe a mixture of 60% rape meal pellets and 40% commercial wood pellets.

TEST EQUIPMENT

A schematic of the test equipment is given in figure 3. A commercially produced residential stove was used for the fuel tests. A cross-section of the stove showing the general arrangement of the firebox inlet air and the location of the thermocouples used inside the stove are given in figure 4. The stove has an underfeed configuration with induced draft (an exhaust fan) and controllable feedrate. Air was introduced at the fire pile and in the flame zone. Both inlets were adjustable.

Type K thermocouples were used to monitor temperatures in the fire pile, and the flame zone. Type J thermocouples were used in the exhaust stack and at various points in the particulate sampling equipment. Exhaust flow was measured by a sharp edge orifice. The pressure differential was monitored with a diaphragm type transducer with electrical output. All transducer outputs were converted to digital form by an A/D converter unit with an RS-232 output. A portable PC provided floppy disk storage of the parameters at intervals selected by the user. Mass burn rate was determined with a digital scale which was capable of continuously weighing the stove and fuel.

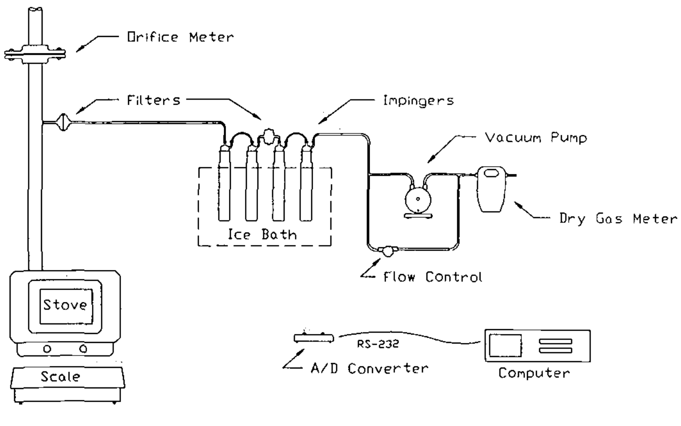

Figure 3–Test equipment.

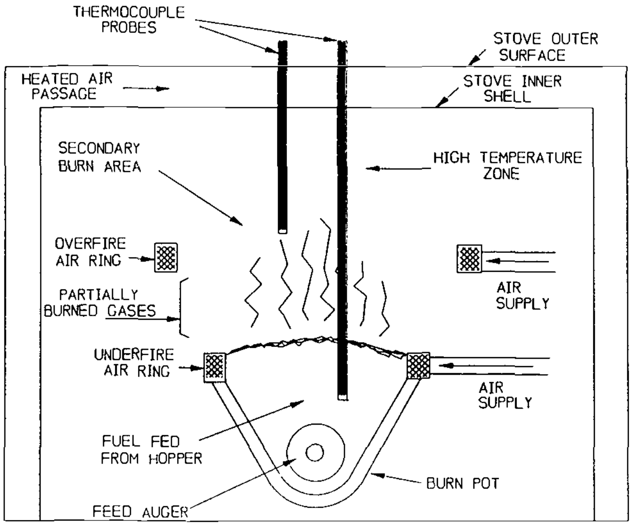

Figure 4–Cross-section of the commercial pellet stove showing the general location of the feed auger, upper and lower air rings, and the thermocouples added for measuring temperatures.

As previously mentioned, some particulate emission regulations already apply to residential woodstoves. The Oregon Department of Environmental Quality Method 7 was selected as the particulate monitoring method most suitable for pellet stoves. This test was essentially the EPA Method 5 (FR 36,24877). Stack gas was sampled at a rate between 0.015 and 0.045 m^3/min (0.53 and 1.59 ft^3/min). The sample was kept heated until it passed through a filter. It was then drawn through a series of cooled impingers where condensable material and water were collected. An Orsat analyzer (Hays Improved) provided O_2, CO_2, and CO concentrations for the calculation of mass flow rate, excess air, and some combustion efficiencies. Particulate matter was determined gravimetrically.

EXPERIMENTAL PLAN

The characterization of the direct combustion of rape products was accomplished with three sets of tests:

1. Two-Fuel Comparison.
   Wood and rape meal were tested for emissions and general performance at three fuel feed rates.
2. Five-Fuel Comparison.
   Wood, meal, residue, blend, and mix were tested for general performance and emissions at a medium fuel feed rate.
3. Durability Test.
   Meal and mix were tested for general performance and deposit formation until definitive information was obtained.

The Two-Fuel Comparison tested the procedures and provided information on the rape meal performance throughout the operating range of the stove. The test was done in one hour "runs" which were repeated until reproducible results were obtained. The same volume feed rate was used for the two fuels, but some variation in mass burn rate resulted from differences in the physical properties of the materials. Inlet air was adjusted for each fuel to obtain the greatest amount of flame above the fire pile. Temperatures and flows were recorded at 1 minute intervals. Two Orsat analysis' were done for each test.

The Five-Fuel Comparison provided qualitative information about the various forms of rape products. This test consisted of one hour burns, with three replicates for each fuel. Again, air flows were adjusted for each run. Monitoring procedures were the same as the previous test.

Finally, the Durability Test produced information concerning the practical problems of utilizing the rape products. The 100% rape meal pellets were burned for 16 hours and then because of poor combustion and excessive "clinkers" the fuel was changed to the 60:40 mixed pellets which were burned for 84 hours. These tests were done at a low to medium feedrate. Temperature and flow parameters were recorded every 30 minutes and Orsat readings were taken every hour.

DISCUSSION AND RESULTS

FUEL PROPERTIES

Investigation of the fuel properties of the pellets began with the determinations presented in Table 1. The heats of combustion and the S, C, and H percentages of these two fuels were calculated from their components.

The densities of Table 1 are bulk densities of the pellets and show the effect of both the pelleting process and the packing of the pellets. The data in Table 1 show that rape pellets have an 8% advantage in energy content based on mass and a 12% advantage based on volume. The residue pellets have 9% less energy per unit mass and 17% less energy per unit volume than the wood based pellets.

The ash contents of the rape products demonstrate the need for long term tests for deposit formation. The relatively high sulphur content of the residue and meal introduces the possibility that sulphur emissions should be determined even though there are no regulations concerning sulphur based emissions.

TWO FUEL COMPARISON

The Two-Fuel Comparison indicated that rape meal pellets cannot be burned as cleanly as wood based pellets, but that their particulate emissions are well within typical regulations (fig. 5). The values given are for comparable mass feed rates of the two fuels. The higher EA requirements of the meal (Table 2) implies that the particulate load for heat outputs equivalent to those of wood may be higher than the values shown. The combustion efficiency in Table 2 refers to the percentage of CO which was converted to CO_2.

TABLE 1. Fuel properties

Density, kg/m^3		639	584	664	637	664
#/ft^3		39.9	36.5	41.4	39.8	41.4
Moisture content*, %		5.5	4.3	7.6	6 0	6 8
Heat of combustion†	KJ/g	19.2	16.5	20.8	20.2	20.2
	Btu/lb	8250	7093	8940	8680	8680
Ash content‡, %		0.20	8.17	7.52	3.77	4.59
Sulphur†, %		0.02	0.36	1.18	0.72	0.72
Carbon†, %		47.55	41.37	46.54	46.94	46.94
Hydrogen†, %		6.75	6.03	7.48	7.19	7.19

Wood was commercial pellets manufactured from waste, soft wood.
Residue was residue of rape recovered from the field following seed harvest.
Meal was pelletized meal of from 12-15% oil content remaining following expression of the aoil from the seed.
Blend was a blend of 60% rape meal pellets and 40% wood pellets.
Mix was a pellet made of 40% red fir shavings and 60% rape meal.
* Determined at University of Idaho, ASAE S352.1.
† Data by Phoenix Chemical Lab, Chicago, Ill. (Gross heat of combustion.)
‡ Determined at University of Idaho, ASTM D1102.

General observations made during the Two-Fuel Comparison were:

1. The emission testing compared favorably with results of certified testing labs (OMNI, 1984).
2. Combustion of the meal pellets was more difficult to control due to the relatively high mass feed rates and a tendency to form combustion chamber deposits.
3. The meal requires more excess air than wood for comparable combustion.

FIVE-FUEL COMPARISON

The Five-Fuel Comparison produced particulate loads shown in figure 6. The values given are normalized to the energy output of the wood pellets by adjusting each fuel by its feed rate, heat of combustion, and excess air according to the relationship:

$$P = \frac{m_{wood}}{m_{fuel}} \frac{\Delta H_{wood}}{\Delta H_{fuel}} \left\{ 1.04 - 0.04 \frac{EA_{fuel}}{EA_{wood}} \right\}^{-1} \{ P_{measured} \},$$

P = Particulate load,
m = mass burn rate,
ΔH = heat of combustion,
EA = excess air.

The factor applied to the EA ratio is the ratio of heat lost through excess air to heat released for average conditions. The application of this equation allows the comparison of the emissions of the fuels for the same useful heat release.

The average conditions during the Five-Fuel Comparison are shown in Table 3. Combustion efficiencies, as measured by the conversion of CO to CO_2, for this test were greater than 97% for all fuels the same as in the Two-Fuel Comparison. Again, the higher EA requirements of the meal implies that it would have a reduced heat output from the appliance because heated EA is exhausted.

The Five-Fuel Comparison revealed serious emission problems associated with burning residue but the meal, especially in blends and mixes with wood, could be an acceptable alternate fuel.

DURABILITY TEST

The Durability Test revealed problems for the rape meal. Deposits (commonly called "clinkers") formed at the

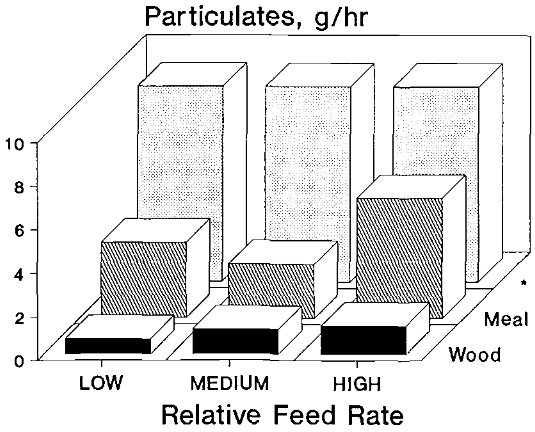

Figure 5–Particulate emissions for the two fuel comparison. •Oregon standards, weighted average.

TABLE 2. Excess air and efficiencies for two fuel comparison

	Wood	Meal
Excess Air, %		
Low Feed Rate	417	342
Medium Feed Rate	48	258
High Feed Rate	50	106
Combustion Efficiency, %		
Low Feed Rate	95	88
Medium Feed Rate	97	94
High Feed Rate	94	95

edges of the fire pile and interfered with the flow of combustion air. Cleaning was required four times during the 16-hour test and 7.84% of the fuel remained as deposits. Due to the underfeed configuration, the deposits tended to obstruct air inlets and resulted in poor combustion. The 60:40 meal and wood blend also formed deposits (5.4%), but they were porous and did not interfere with combustion to the same extent as the meal deposits. Maintenance was required three times during the 84-hour test of the MIX.

The Durability Test exposed the practical problems of utilization of rape meal in conventional stoves but also the potential of the fuel as a component of blended and mixed fuels.

ECONOMICS

Currently, the market for pellet raw material is met with by-products of the lumber industry. These include mill by-products and a portion of logging residues. The mill by-products are those which are unacceptable as pulp material. The logging residues are expensive to collect but their removal is a requirement of many public land timber contracts. The cost at the pelleting site for these materials is generally limited to transportation and chipping costs. A study done for BPA (Vranzian et al., 1987) found prices paid for wood fuels in the Pacific Northwest vary from 0 to $24.25 /t (0 to $22 /ton) (dry weight basis). Thus, the current value of rape products for direct combustion is negligible except in isolated cases where a pellet market exists far from lumber industry locations.

The increasing use of pellets implies that sources of no-cost raw materials will not meet future demand. In this case, prices may rise to the cost of gathering logging residues whose collection is not currently required in timber contracts. This would create an in-woods price of between $25 and $45 /t ($23 and $41 /ton) for residues (Envirosphere, 1986) and with average processing and transportation costs of $12 /t ($11 /ton), a total price of $57 /t ($52 /ton) of pellettable material is possible.

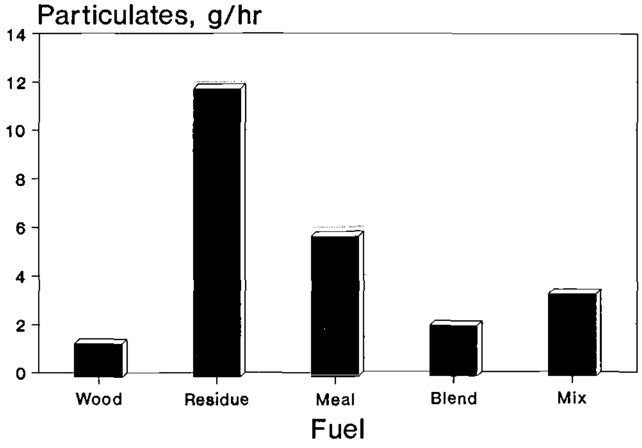

Figure 6–Particulate emissions for the five-fuel comparison.

TABLE 3. Averages, five fuel comparison

Fuel	Feed Kg/hr	Rate lb/hr	EA %	CO_2 %	O_2 %	CO %
Wood	1.99	4.39	48	9.9	6.0	0.2
Residue	1.61	3.55	177	5.9	12.6	0.3
Meal	1.54	3.40	154	6.8	11.5	0.1
Blend	1.87	4.12	100	8.5	8.8	0.1
Mix	1.89	4.17	67	10.5	7.3	0.0

Although the economic picture for rape product utilization is not promising, the characteristics of the rape seed plant offers the potential for a unique utilization – that of a "total energy crop." The primary product, the oil, can be used as a diesel fuel extender (Peterson, 1988). If the meal is utilized as pellet material, the entire harvested portion of a rapeseed crop would be used for energy production. Such a crop could be grown on the currently subsidized "set-aside" land without impacting any existing agricultural markets. Thus, an unproductive subsidy could be used to finance a new and unique source of energy.

CONCLUSIONS

Testing of rape products in a conventional residential stove has produced the following conclusions;

1. Rape residue can be pelleted and it burns well, but emissions and deposit formation in a conventional stove are unacceptable.
2. Rape meal can be pelleted. The procedure does not substantially change the properties of the meal. The physical characteristics of meal pellets are inferior to those of wood based pellets but they can be burned in a conventional stove. Emissions are acceptable but deposit formation limits the utility of pure meal pellets when used with underfeed configurations.
3. The blending of meal and wood produces excellent pellets which burn with low emissions and little deposit formation.
4. The burning of meal pellets mixed with wood pellets is feasible – emissions and deposit formation are acceptable.

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