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THE OIL HEATING ASSOCIATION OF CANADA

CLEAN AIR PROGRAM

PHASE VI: ASSESSMENT OF BURNER PERFORMANCE

by

T. D. Brown

Canadian Combustion Research Laboratory

Energy Research Laboratories

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ABSTRACT

Two Evaluation Indices are defined to facilitate the assessment of burner performance. These indices, derived from performance data measured during steady running (the Steady Running Index) and transient operation, (the Transient Index) have values between 0 and 100. The Steady Running Index attaches greatest importance to the carbon dioxide and soot content of the flue gases and a lesser importance to the carbon monoxide and nitric oxide content of the flue gas. The Transient Index attaches equal importance to the soot and carbon monoxide produced on both start-up and shut-down.

Comparison of burner performance based on these indices shows that the burners equipped with flame retention heads offer a superior performance to the swirl and standard-head burners examined in the test program. The use of a clutch-coupling is seen to improve the transient performance of all the burners whereas the use of a high-speed motor has no effect. The effect of fuel type (aromaticity) is most marked on the retention-head burners.

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*Prepared for the Equipment and Service Committee of the Oil Heating Association of Canada, Chairman, C.S. James.

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L'ASSOCIATION DU CHAUFFAGE A L'HUILE DU CANADA

PROGRAMME DE PURIFICATION DE L'AIR

PHASE VI: L'EVALUATION DE L'EFFICACITE DE BRULEUR*

par

T. D. Brown**

RESUME

On a établi les valeurs de deux index d'évaluation pour mieux déterminer l'efficacité de brûleur. Les valeurs de ces index, obtenues par les données relevées pendant un fonctionnement constant (Index du fonctionnement constant) et un fonctionnement intermittent (Index intermittent), s'échelonnent de 0 à 100. L'Index du fonctionnement constant tient compte principalement de l'acide carbonique et de la suie contenu dans le gaz de fumée et tient moins compte de l'oxyde de carbone et du bioxyde d'azote. L'Index intermittent, lui, attache une même importance à la suie et à l'oxyde de carbone produit au démarrage et à l'arrêt.

Lors du programme d'essai on a comparé, en se basant sur ces Index, le rendement de brûleur. On s'est aperçu que les brûleurs munis de têtes de rétention de flamme offraient un rendement supérieur aux brûleurs a serpentins et aux bruleurs a têtes standard. L'utilisation d'un accouplement à débrayage semble améliorer le rendement intermittent de tous les brûleurs tandis que l'utilisation d'un moteur à haute vitesse ne produit aucun effet. On remarque que l'utilisation d'un combustible type (aromaticité) a un plus grand effet sur les brûleurs à têtes de rétention.

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*Préparé pour le Comité du service et de l'équipement de l'Association du chauffage à l'huile du Canada, Président C. S. James.

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CONTENTS

INTRODUCTION

During the summer of 1972 the Oil Heating Association of Canada requested the Canadian Combustion Research Laboratory to undertake a comparative evaluation of oil burning equipment currently on the market for residential heating. The principal objective of this test program was the characterization of burner performance in terms of fuel efficiency and pollutant emission. Details of the test equipment and experimental procedures used in this program have been described in Mines Branch Investigation Report IR 73-32[1]. The experimental data from the four test furnaces has been presented in Investigation Reports IR 73/33, IR 73/43, IR 74/43 and IR 74/45.

To facilitate comparison between the test burners numerical ratings (Evaluation Indices) have been calculated from the performance data under both steady state and transient operation. These are called the Steady Running Index (SRI) and the Transient Index (TI).

DERIVATION OF THE EVALUATION INDICES

The Steady Running Index (SRI)

This index has four component inputs which are derived from measured performance parameters. One component is derived from the carbon dioxide content of the flue gases and is an indirect measure of the efficiency of fuel utilization. The other three components are derived from measurements of individual pollutant emissions i.e. smoke, nitric oxide and carbon monoxide. The component derived from the smoke measurement is a direct measure of the quantity of soot produced in the flame whereas the components derived from nitric oxide and carbon monoxide are considered relative to standard emissions that can be achieved by good practice. It should be remembered that soot formation in a flame will also have an indirect effect on fuel efficiency by virtue of the insulating effect of soot deposited on the heat transfer surfaces of the appliance.

The four components are grouped together with different weightings that reflect their relative importance:

Component	Weighting Factor
Carbon Dioxide	500
Smoke	400
Nitric Oxide	200
Carbon Monoxide	100

The highest importance is attached to the two factors which affect the efficiency of fuel utilization (carbon dioxide and soot) with a slight emphasis on the carbon dioxide level. A lower importance is attached to the emissions of carbon monoxide and nitric oxide.

A numerical value is calculated from each performance measurement as follows.

Carbon Dioxide

$$\text{Numerical Value, } N_{CO_2} = 500 \left[\frac{CO_2 \ \% \ \frac{v}{v} \ \text{dry}}{CO_{2_{max}} \ \% \ \frac{v}{v} \ \text{dry}} \right]$$

where $CO_{2_{max}}$ % $\frac{v}{v}$ dry is the CO_2 concentration (%) in the dry stoichiometric combustion products calculated from the known Carbon:Hydrogen ratio of the fuel. For the test fuel used in the OHA program this has a value of 15.50.

Smoke

$$\text{Numerical Value, } N_s = 400 \left[\frac{9 - \text{Measured Smoke No.}}{9} \right]$$

The smoke number is measured on the Shell-Bacharach scale and has a maximum value of 9.

Carbon Monoxide

$$\text{Numerical Value, } N_{CO} = 200 \left[\frac{1000 - \text{ppm CO}}{1000} \right]$$

The selection of a maximum value of 1000 ppm CO is arbitrary.

Nitric Oxide

$$\text{Numerical Value, } N_{NO} = 100 \left[\frac{K - \text{NO (lb/1000 lb fuel)}}{K} \right]$$

K is a constant which is equal to the mean nitric oxide emission (lb/1000 lb fuel) of all the burners at a given firing rate and, therefore, represents an emission level that can be achieved.

The following values of K are used in this evaluation index:

Firing Rate	K Value (Standard NO Emission lb/1000 lb fuel)
0.5 US gph	1.75
0.75 US gph	2.00
1.00 US gph	2.5

The Steady Running Index is given by:

$$SRI = \frac{1}{12} \left[N_{CO_2} + N_s + N_{CO} + N_{NO} \right]$$

The SRI will have a value between 0 and 100 with the 'best' performance represented by numbers approaching 100.

In practical combustion systems, where carbon monoxide, smoke and nitric oxide are always formed and the combustion air level is always above the stoichiometric value; the SRI will always be below 100.

The effect of variations in these component inputs on the steady running index are shown in Figures 1 and 2 where the weighting given to excess air level and smoke number are clearly shown to dominate this evaluation index.

The Transient Index (TI)

This index has four components which come from measured Smoke Indices (SI) and peak carbon monoxide concentrations on both start-up and shut-down. Each performance measurement is assigned an equal weighting and the numerical values are calculated as follows:

N_1 (smoke index, start-up) $= \left[\frac{10 - \text{SI measured}}{10} \right] (100)$

N_2 (peak CO, start-up) $= \left[\frac{0.1 - \text{CO \% peak}}{0.1} \right] (100)$

N_3 (smoke index, shut-down) $= \left[\frac{10 - \text{SI measured}}{10} \right] (100)$

N_4 (peak CO, shut-down) $= \left[\frac{0.1 - \text{CO \% peak}}{0.1} \right] (100)$

Transient Index $= \frac{N_1 + N_2 + N_3 + N_4}{4}$

The Transient Index will have a value between 0 and 100.

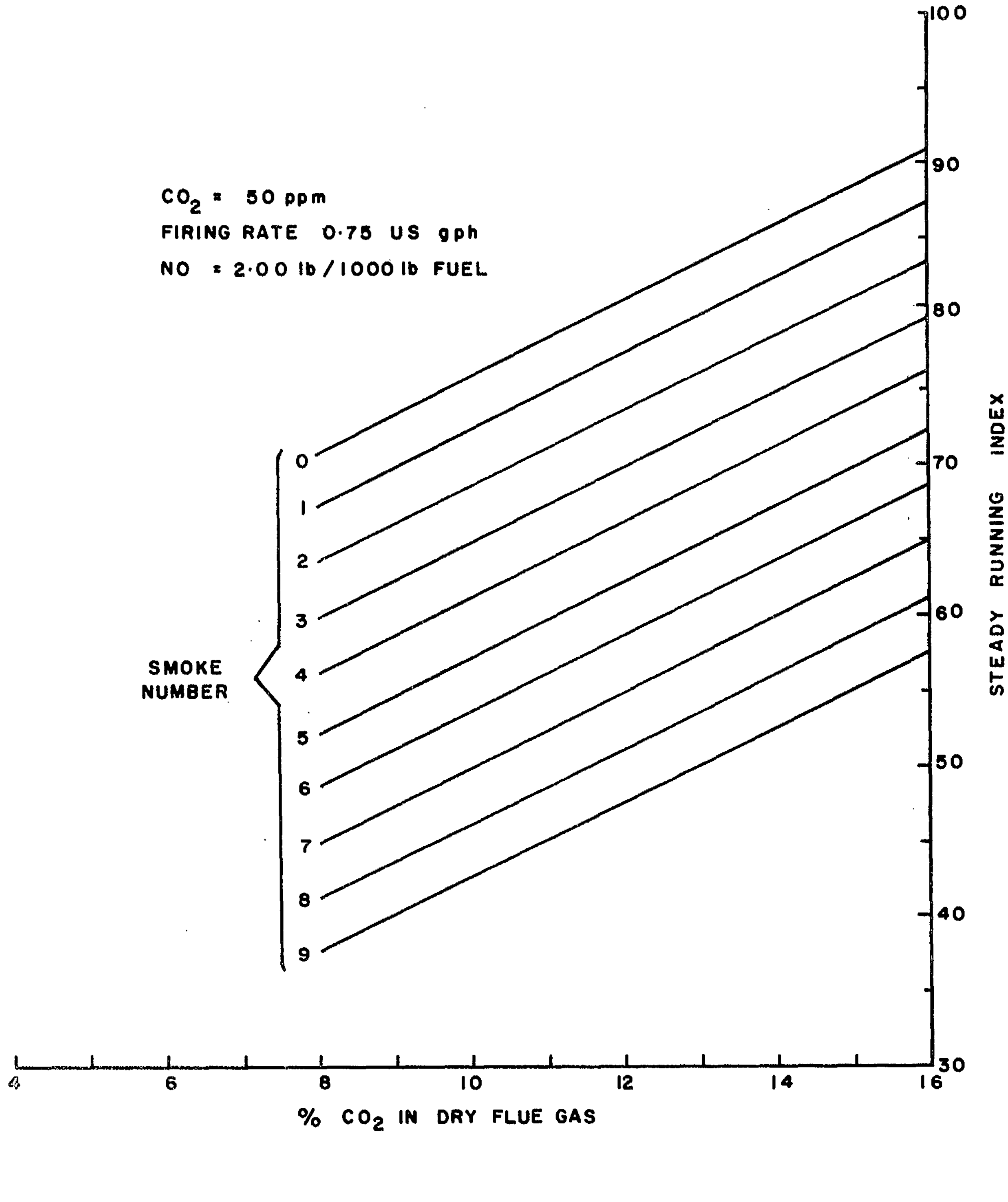

Figure 1. The influence of carbon dioxide level and smoke number on the steady running evaluation index.

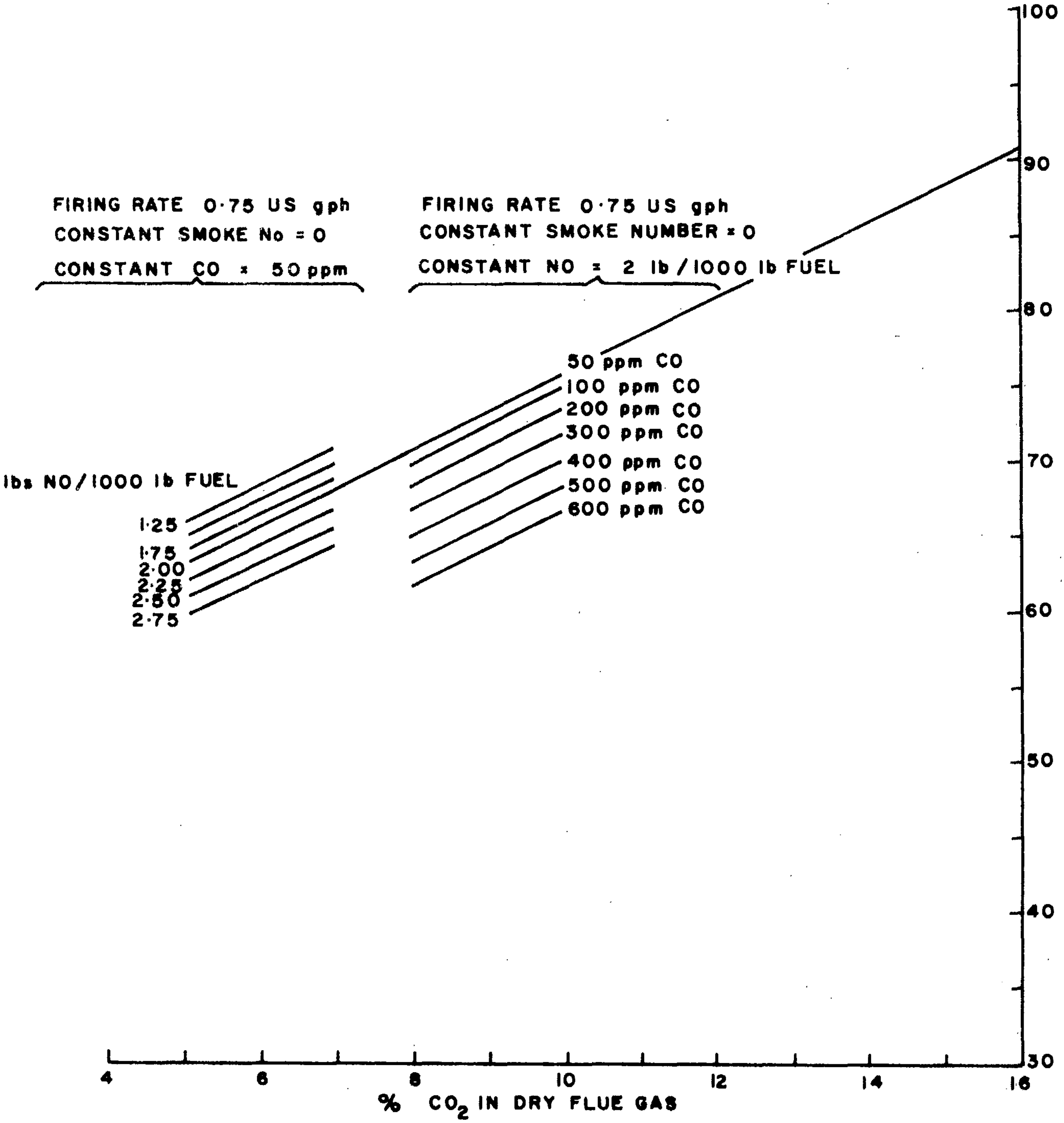

Figure 2. The influence of carbon monoxide and nitric oxide on the steady running evaluation index.

In the transient index equal importance has been attached to smoke index and peak carbon monoxide concentrations during both start-up and shut-down.

All subsequent discussion in this report relates to the evaluation indices calculated in the manner described above. The terminology "better performance" and "higher evaluation index" can be considered synonymous. Small changes in the weightings of the individual components will not change trends of the conclusions.

The Standard Steady Running Index

It is considered that a combustion standard of 9% CO_2, a smoke number of one, a CO concentration of 50 ppm and a standard NO emission (K factors given on page 3) represents a modestly satisfactory steady running performance. This corresponds to an SRI of 70.0. and is described as the "standard" performance.

STEADY RUNNING PERFORMANCE

The Steady Running Indices are presented in Tables A1-A4 inclusive of the Appendix to this report and are regrouped in the following sections to show the effects of furnace type, firing rate, burner design and furnace draft. In this discussion the standard draft is -0.02" WC;reduced draft is +0.05"WC and increased draft is -0.05" WC.

The Effect of the Furnace

The number of burner/firing rates meeting the standard SRI is illustrated in Table 1.

TABLE 1

The Effect of the Furnace on Burner Performance

Furnace	The Number of Test Combinations with SRI > 70		
	At The Standard Draft	At The Increased Draft	At The Reduced Draft
Grimsby Warm Air	9 of 18	8 of 18	5 of 16
Anthes Warm Air	10 of 18	7 of 18	10 of 18
Aero Hot Water Heater	11 of 18	13 of 18	12 of 18
American Standard Hot Water Boiler	13 of 18	9 of 17	7 of 18

During the entire series of tests one half of the burner/firing rate/furnace combinations were capable of achieving combustion conditions equivalent to a Steady Running Index above 70.

It appears from Table 1 that the temperature of the combustion chamber walls affected the burner performance. The stainless steel combustion chamber of the Grimsby warm air furnace led to an overall poor performance for all the burners under all draft conditions.

At the reduced draft condition the fall in performance in the Grimsby furnace was attributed to the chilling action of the combustion chamber walls on soot formed in the flame. In the Anthes furnace benefits due to the elimination of the air infiltration known to occur at the standard and increased draft condition coupled with the continued combustion of soot in the hot combustion chamber to maintain the standard of performance.

The Effect of Burner Design

Burner Head Design

The six burners nominated for inclusion in the test program could be divided into three categories in terms of the burner head design.

	Category	Burner	
(1)	Retention Head	Beckett	3450 rpm
		Aero	3450 rpm
		Aero	1725 rpm
(2)	Swirl Head	Anthes	1725 rpm
(3)	Standard Head	Terry	1725 rpm
		Beckett	1725 rpm

The results of the Steady Running Index calculations are grouped in Table 2 in terms of the burner head design.

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(3)	Standard Head	Terry	1725 rpm
		Beckett	1725 rpm

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TABLE 2

The Effect of Burner Design

Burner	No. of Test Combinations with SRI 73.4		
	At the Standard Draft	At the Increased Draft	At the Reduced Draft
Retention Head Burners			
Beckett 3450 rpm	10 of 12	9 of 11	5 of 12
Aero 3459 rpm	9 of 12	5 of 12	8 of 12
Aero 1725 rpm	10 of 12	9 of 12	8 of 12
Swirl Head Burner			
Anthes 1725 rpm	7 of 12	7 of 12	5 of 11
Standard Head Burners			
Terry 1725 rpm	4 of 12	3 of 12	5 of 11
Beckett 1725 rpm	3 of 12	4 of 12	4 of 12

It is apparent that the retention-head burners offer a better performance at the standard draft condition than the other burner types and maintain this superiority under modified draft conditions.

Motor Speed

The only difference in design between the Aero 3450 rpm and the Aero 1725 rpm burners is in the motor speed. No significant performance difference between the burners is apparent at the standard draft condition.

The Effect of Firing Rate

The Steady Running Indices of each burner at the firing rates tested are shown in Table 3.

TABLE 3

The Effect of Firing Rate

Burner	Firing Rate US gph	Steady Running Index: At the Standard Draft	Steady Running Index: At the Increased Draft	Steady Running Index: At the Reduced Draft
Retention Head Burners				
Beckett 3450 rpm	0.5	67.0	65.8	62.8
	0.75	76.2	74.5	68.7
	1.00	79.4	76.5	70.3
Aero 3450 rpm	0.5	69.4	68.2	74.1
	0.75	75.7	70.2	57.0
	1.00	77.0	75.8	69.2
Aero 1725 rpm	0.5	70.7	70.7	74.0
	0.75	73.8	72.1	73.3
	1.00	78.2	77.0	68.0
Swirl Head Burner				
Anthes 1725 rpm	0.5	51.5	49.4	48.3
	0.75	72.4	72.3	69.9
	1.00	78.9	77.2	78.2*
Standard Head Burners				
Terry 1725 rpm	0.5	59.4	60.2	65.1*
	0.75	63.5	67.4	66.7
	1.00	69.2	69.4	65.5
Beckett S 1725 rpm	0.5	52.9	50.7	49.7
	0.75	69.8	70.0	71.8
	1.00	67.9	66.2	63.2

*This value does not include tests in the Anthes furnace which were abandoned because of excessive smoke production. The Steady Running Index will be lower than that quoted.

At the standard furnace draft condition the burner performance improved continuously with increased firing rate with the exception of the Beckett S burner (0.75 → 1.00 US gph). One retention head burner met the Steady Running Index standard at the lowest firing rate at all draft conditions; the other retention head burners of similar design were grouped around the standard Steady Running Index.

At the increased draft condition a pattern of continuously improved performance with increased firing rate prevailed. At the reduced draft condition there was not a consistent trend.

The Effects of Draft Variation

The usual effect of increased furnace draft was to increase the excess-air level and, occasionally, to increase the smoke number. The usual effect of reduced draft was to decrease the excess-air level and to increase the smoke number.

It can be anticipated, therefore, that increased draft will lead to a reduction in the SRI, reduced draft may lead to either an increase or a decrease in the SRI. Under reduced draft conditions where an increase in the SRI occured the decreased excess-air has over compensated for any increase in smoke production i.e. $500\Delta N_{CO_2}$[1/] is positive and is greater than $400\Delta N_s$. [2/] If the SRI decreased under reduced draft condition then the converse was true i.e. $500\Delta N_{CO_2}$ is positive and is less than $400\Delta N_s$. The ability of a burner to operate without smoke production (which would lower the SRI) at the reduced draft condition was a function of both the pressure drop across the burner air-register and the excess-air level at the standard draft condition. Since all of the burners operate at essentially the same blast tube pressure (at the same firing rate) it can be expected that the burners showing the highest SRI at the standard draft conditon will show decreases in SRI under reduced draft conditions if they generate significant smoke.

1/ N_{CO_2} means change in the CO_2 Numerical Value defined on page 3.

2/ N_s means change in the smoke Numerical Value defined on page 3.

At a firing rate of 0.5 US gph all the burners showed a similar change (about 5 units) in the SRI and it must be concluded that the burners are all equally stable with respect to draft at this firing rate. The best performance was achieved by the three retention head burners.

At a firing rate of 0.75 US gph all the retention-head burners had a decreased SRI at both modified draft conditions whereas the standard-head burners had an increase under the same modified draft. At this firing rate, the overall best performance was achieved by two of the three retention-head burners; one standard-head burner exceeded the performance of the fourth retention-head burner.

At a firing rate of 1.00 US gph all the burners perform in a similar fashion under different draft conditions. The SRI reduces with both increased and decreased draft. The swirl and retention-head burners performed best at this firing rate. In general, the retention-head burners maintained the overall highest SRI under all draft conditions.

The Effect of Fuel Type

In order to assess the effect of fuel quality on burner performance the high aromatic blend used throughout the test program was replaced with a conventional Ottawa Valley No. 2 fuel oil. Using this fuel the performance of the burners was examined at the highest firing rate in the American Standard Boiler. The comparative combustion results as reported in Table A13 and the analyses of the two fuels in Table A14 of Appendix A to this report.

It can be seen that use of the low aromatic fuel led to an improved burner performance at the standard draft condition. The minimum excess-air level that could be achieved without smoke production was decreased by use of the low aromatic fuel for the retention and swirl head burners but remained unchanged for the standard head burners. This reduction of excess-air led to an improvement in SRI for the retention head burners.

START-UP AND SHUT-DOWN PERFORMANCE

The transient state indices (TI) are presented in Tables A5-A12 of Appendix A to this report.

The Effect of the Furnace

The test data are grouped in Table 4 to illustrate the effect of the furnace on the Transient Index.

TABLE 4

Transient Index (TI): The Effect of the Furnace

Furnace	Firing Rate US gph	Transient Index: Average for all Burners		
		At the Standard Draft	At the Increased Draft	At the Reduced Draft
Grimsby	0.5	52.7	56.2	51.0
Stainless Steel	0.75	77.3	87.4	69.9
Combustion Chamber	1.00	81.9	83.4	66.8
Anthes	0.5	93.0	83	88 1/
Refractory	0.75	91.6	92.1	93.2 1/
Combustion Chamber	1.00	91.4	93.0	82.9 1/
American Standard	0.5	79.4	83.2	65.8
Refractory	0.75	84.4	92.8	72.3
Combustion Chamber	1.00	84.4	90.0	81.7
Aero	0.5	88.0	81.6	67
Refractory	0.75	85.8	85.6	59.8
Combustion Chamber	1.00	87.5	91.5	74.5

1/ Because of excessive smoke production a furnace draft of +0.025" WC was used instead of +0.05" WC.

At the standard draft condition the Transient Index was consistently low in the Grimsby furnace. This is attributed to the lower surface temperatures of the stainless steel combustion chamber chilling the unburnt fuel at both the instant of ignition and shut-down to a greater degree than occurs in a refractory lined chamber. The relatively high thermal capacity of the refractory implies a slower cooling rate which allows any residual fuel to burn completely (without smoke or CO production) after shut-down.

At the reduced draft condition, the data for the Anthes furnace was obtained at a draft of +0.025" WC rather than the +0.05" WC used in all other furnaces because of the excessive smoke production at the higher of the two positive draft conditions. Disregarding the results for the Anthes furnace it is apparent that throughout the test series the Transient Index is consistently lower at the reduced draft condition.

The Effects of Burner Design

Burner Head Design

At the standard draft condition, the best start-up and shut-down performance was offered by the retention head burners. This can be ascribed to the superior air-fuel mixing generated by these heads (as evidenced by the superior Steady Running Index) giving better combustion during transient operation. A similar pattern prevailed at the increased draft condition but was less well defined at the reduced draft condition. (See Table 5).

Clutch-Coupling

The summary comparison in Table 6 shows that the clutch-coupling produces an improvement in Transient Index in all furnaces at all firing rates under all draft conditions with the sole exception of the Grimsby furnace at the lowest firing rate.

TABLE 5

The Transient Index(TI): A Comparison of Burners

Burner	Firing Rate US gph	Transient Index: Average for all At the Standard Draft	At the Increased Draft	At the Reduced Draft
Beckett 3450 rpm	0.5	91.8	93.7	74.4
	0.75	86.5	88.7	73.
	1.00	91.6	94.5	85.3
Aero 3450 rpm	0.5	98.3	97.2	98.3
	0.75	95.2	98.9	98.8
	1.00	96.8	99.5	92.4
Aero 1725 rpm	0.5	93.8	90.7	75.1
	0.75	95.16	92.	52.2
	1.00	90.3	95.6	
Anthes 1725 rpm	0.5	58.6	48.1	48.8
	0.75	83.0	88.0	78.3
	1.00	86.7	85.5	85.1
Terry 1725 rpm	0.5	75.2	76.1	66.8
	0.75	82.0	87.8	72.4
	1.00	78.2	82.8	60.8
Beckett S 1725 rpm	0.5	68.3	73.9	52.6
	0.75	67.1	83.0	63.3
	1.00	78.7	86.3	70.0

TABLE 6

The Effectiveness of a Clutch-Coupling in Different Furnaces

Furnace	Firing Rate US gph	Ratio: Transient Index With Clutch-Coupling / Transient Index Without Clutch-Coupling — Average Values for All Burners: At the Standard Draft	At the Increased Draft	At the Reduced Draft
Grimsby	0.5	0.98	0.99	2.82
	0.75	1.35	1.15	1.24
	1.00	1.18	1.04	-
Anthes	0.5	1.09	1.12	1.33
	0.75	1.05	1.04	1.19
	1.00	1.02	1.00	1.08
American Standard	0.5	1.00	1.21	1.04
	0.75	1.17	1.12	1.47
	1.00	1.15	1.22	1.59
Aero	0.5	1.25	1.03	1.02
	0.75	1.15	1.0	1.46
	1.00	1.44	1.23	1.57

Motor Speed

Without a clutch-coupling it did not appear that the motor speed had any significant effect on the Transient Index at any draft condition. The effectiveness of a clutch-coupling appeared to be enhanced when it was used in conjunction with a high-speed motor. This observation requires verification.

TABLE 7

The Effect of Motor Speed On Clutch-Coupling Performance
(Measurements at the Standard Draft Condition)

Burner	Firing Rate US gph	Ratio: Transient Index With Clutch-Coupling / Transient Index Without Clutch-Coupling (Average Values for All Furnaces)
Aero 3450 rpm	0.5	1.46
	0.75	1.50
	1.00	1.69
Aero 1725 rpm	0.5	1.37
	0.75	1.18
	1.00	1.15
All Burners	0.5	1.08
	0.75	1.18
	1.00	1.19

The reasons for improved clutch-coupling performance on burners equipped with high-speed motors were discussed in an earlier report[3].

The Effect of Firing Rate

The swirl and standard-head burners tested showed a Transient Index which increased with firing rate.

The retention-head burners did not show this distinctive pattern; they did, however, show the lowest Transient Indices.

CONCLUSIONS

1. The steady running performance of all the burners improved with increased firing rate in all furnaces. It was marginally better in the refractory lined furnaces than in the single furnace equipped with a stainless steel combustion chamber. This margin of superiority disappeared when air infiltrated to the flame in the refractory lined furnaces.

2. The retention-head burners tested in this program offered a superior performance to the standard-head burners at all firing rates. The margin of superiority was smallest at the lowest firing rate where all the test burners performed at their lowest standard. If improved domestic insulation standards create a demand for lower capacity furnaces the overall performance of low-firing rate burners (<0.75 US gph) must be improved.

3. There was no significant improvement in steady or transient running performance due to the speed of the motor.

4. The incorporation of a clutch-coupling led to a significant improvement in the start-up and shut-down performance of all the burners. This improvement was most marked on burners equipped with high-speed motors.

5. The performance of the retention-head burners improved with reduced aromatic content in the fuel whereas the inferior performance of the standard-head burners remained unchanged.

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APPENDIX A: REDUCED PERFORMANCE DATA

TABLE A1

STEADY RUNNING INDEX

Grimsby Furnace

Burner	Firing Rate US gph	SRI At the Standard Draft	SRI At the Increased Draft	SRI At the Reduced Draft
Beckett 3450 rpm	0.5	60.7	59.5	60.5
	0.75	74.0	71.1	60.3
	1.00	78.5	76.5	76.6
Aero 3450 rpm	0.5	69.5	68.2	59.4
	0.75	79.1	69.5	63.0
	1.00	75.6	75.4	71.9
Aero 1725 rpm	0.5	74.2	76.6	80.2
	0.75	79.1	76.3	72.8
	1.00	79.4	78.1	62.7
Anthes 1725 rpm	0.5	25.3	25.0	36.5
	0.75	65.6	65.3	62.7
	1.00	76.4	76.6	-
Terry 1725 rpm	0.5	43.0	45.4	-
	0.75	56.1	68.9	67.1
	1.00	61.2	60.2	54.1
Beckett 1725 rpm	0.5	39.5	37.4	35.1
	0.75	77.3	75.8	74.6
	1.00	58.6	57.6	49.3

Note that the SRI for a burner operating at 9% CO_2, a smoke number of 1, a CO concentration of 50 ppm and a standard NO emission (see K factors on page 3) is 70.0.

TABLE A2

STEADY RUNNING INDEX

Anthes Furnace

Burner	Firing Rate US gph	SRI At the Standard Draft	SRI At the Increase Draft	SRI At the Reduced Draft
Beckett 3450 rpm	0.5	59.5	66.7	41.9
	0.75	72.8	71.9	70.1
	1.00	77.0	71.0	56.8
Aero 3450 rpm	0.5	61.7	65.1	76.2
	0.75	72.1	63.8	12.6
	1.00	65.9	65.2	41.4
Aero 1725 rpm	0.5	70.6	69.2	74.2
	0.75	66.9	65.8	82.2
	1.00	74.2	71.5	74.7
Anthes 1725 rpm	0.5	67.3	64.5	51.6
	0.75	75.2	73.2	76.9
	1.00	79.6	75.6	78.6
Terry 1725 rpm	0.5	73.3	68.6	72.8
	0.75	72.4	72.6	77.8
	1.00	76.4	77.7	79.7
Beckett 1725 rpm	0.5	56.3	52.9	63.4
	0.75	64.4	65.9	72.8
	1.00	69.5	62.6	61.4

Note that the SRI for a burner operating at 9% CO_2, a smoke number of 1, a CO concentration of 50 ppm and a standard NO emission (see K factors on page 3) is 70.0.

TABLE A3

STEADY RUNNING INDEX

Aero Hot Water Heater

Burner	Firing Rate US gph	SRI At the Standard Draft	SRI At the Increased Draft	SRI At the Reduced Draft
Beckett 3450 rpm	0.5	75.2	71.1	68.4
	0.75	80.4	76.2	81.8
	1.00	87.3	84.4	89.1
Aero 3450 rpm	0.5	73.1	70.9	79.7
	0.75	78.9	80.3	76.5
	1.00	87.9	86.3	80.0
Aero 1725 rpm	0.5	70.6	73.2	83.1
	0.75	76.2	73.6	82.9
	1.00	80.7	82.2	77.6
Anthes 1725 rpm	0.5	64.9	63.3	68.3
	0.75	78.2	78.5	82.0
	1.00	79.8	78.0	73.5
Terry 1725 rpm	0.5	68.4	70.5	67.0
	0.75	68.9	67.0	71.2
	1.00	67.5	69.7	70.4
Beckett S 1725 rpm	0.5	54.9	57.9	54.6
	0.75	62.8	57.9	54.6
	1.00	69.2	72.1	67.1

TABLE A4

STEADY RUNNING INDEX

American Standard Hot Water Boiler

Burner	Firing Rate US gph	SRI At the Standard Draft	SRI At the Increased Draft	SRI At the Reduced Draft
Beckett 3450 rpm	0.5	72.5	-	80.4
	0.75	77.4	78.9	62.6
	1.00	74.9	73.9	58.6
Aero 3450 rpm	0.5	73.2	68.5	81.1
	0.75	72.8	67.1	75.8
	1.00	78.5	76.1	83.3
Aero 1725 rpm	0.5	67.5	63.6	58.6
	0.75	72.8	72.7	55.3
	1.00	78.4	76.3	57.1
Anthes 1725 rpm	0.5	48.4	44.7	36.7
	0.75	70.7	72.0	57.8
	1.00	79.8	78.5	82.6
Terry 1725 rpm	0.5	52.9	56.3	55.6
	0.75	56.5	61.2	44.9
	1.00	71.7	69.9	57.9
Beckett S 1725 rpm	0.5	60.7	54.6	45.7
	0.75	74.8	72.1	77.9
	1.00	74.4	72.6	74.8

TABLE A5

TRANSIENT INDEX
(With a Clutch Coupling)

Grimsby Furnace

Burner	Firing Rate US gph	TI At the Standard Draft	TI At the Increased Draft	TI At the Reduced Draft
Beckett 3450 rpm	0.5 0.75 1.00			
Aero 3450 rpm	0.5 0.75 1.00			
Aero 1725 rpm	0.5 0.75 1.00	95 97 93	97 96 94	94 90 69
Anthes 1725 rpm	0.5 0.75 1.00	19 76 93	13 82 84	9 70 88
Terry 1725	0.5 0.75 1.00	40 80 72	42 89 73	45 64 59
Beckett 1725 rpm	0.5 0.75 1.00	57 56 69	72 83 83	56 50 52

TABLE A6

TRANSIENT INDEX

(With a Clutch Coupling)

Anthes Furnace

Burner	Firing Rate US gph	TI At the Standard Draft	TI At the Increased Draft	TI At the Reduced Draft
Beckett 3450 rpm	0.5 0.75 1.00			
Aero 3450 rpm	0.5 0.75 1.00			
Aero 1725 rpm	0.5 0.75 1.00	96 99 90	98 97 97	91 97 90
Anthes 1725 rpm	0.5 0.75 1.00	85 78 87	57 85 88	77 84 85
Terry 1725 rpm	0.5 0.75 1.00	99 98 97	93 94 94	96 95 73
Beckett 1725 rpm	0.5 0.75 1.00			

TABLE A7

TRANSIENT INDEX

(With a Clutch-Coupling)

Aero Hot Water Heater

Burner	Firing Rate US gph	TI At the Standard Draft	TI At the Increased Draft	TI At the Reduced Draft
Beckett 3450 rpm	0.5	96	94	70
	0.75	83	93	68
	1.00	89	94	77
Aero 3450 rpm	0.5	100	99	98
	0.75	97	98	97
	1.00	97	99	87
Aero 1725 rpm	0.5	100	76	46
	0.75	99	82	(-40)
	1.00	97	97	64
Anthes 1725 rpm	0.5	71	65	74
	0.75	92	93	85
	1.00	89	90	80
Terry 1725 rpm	0.5	84	84	73
	0.75	76	79	82
	1.00	75	87	65
Beckett 1725 rpm	0.5	77	70	41
	0.75	68	68	66
	1.00	79	82	73

TABLE A8

TRANSIENT INDEX

(With a Clutch Coupling)

American Standard Hot Water Boiler

Burner	Firing Rate US gph	TI At the Standard Draft	TI At the Increased Draft	TI At the Reduced Draft
Beckett 3450 rpm	0.5 0.75 1.00	87 90 94	93.0 84.5 95.0	79 78 93
Aero 3450 rpm	0.5 0.75 1.00	96 93 96	95 100 100	99 100 98
Aero 1725 rpm	0.5 0.75 1.00	85 86 80	91 93 94	69 61
Anthes 1725 rpm	0.5 0.75 1.00	59 86 78	57 93 80	35 74 87
Terry 1725 rpm	0.5 0.75 1.00	78 74 69	84 88 77	52 47 46
Beckett 1725 rpm	0.5 0.75 1.00	72 77 88	79 98 94	61 75 85

TABLE A9

TRANSIENT INDEX

(Without a Clutch Coupling)

Grimsby Furnace

Burner	Firing Rate US gph	TI At the Standard Draft	TI At the Increased Draft	TI At the Reduced Draft
Beckett 3450 rpm	0.5 0.75 1.00			
Aero 3450 rpm	0.5 0.75 1.00			
Aero 1725 rpm	0.5 0.75 1.00	64 62 67	65 64 78	47 36
Anthes 1725 rpm	0.5 0.75 1.00	66 81 81	47 71 86	-12 72 -15
Terry 1725 rpm	0.5 0.75 1.00	84 85 69	69 86 81	57 73 64
Beckett 1725 rpm	0.5 0.75 1.00	71 75 61	46 84 74	

TABLE A10

TRANSIENT INDEX

(Without a Clutch Coupling)

Anthes Furnace

Burner	Firing Rate US gph	TI At the Standard Draft	TI At the Increased Draft	TI At the Reduced Draft
Beckett 3450 rpm	0.5 0.75 1.00			
Aero 3450 rpm	0.5 0.75 1.00			
Aero 1725 rpm	0.5 0.75 1.00	85 85 83	84 91 93	42 58 47
Anthes 1725 rpm	0.5 0.75 1.00	85 85 94	49 82 94	81 88 92
Terry 1725 rpm	0.5 0.75 1.00	87 92 91	89 93 93	76 87 92
Beckett 1725 rpm	0.5 0.75 1.00			

TABLE A11

TRANSIENT INDEX

(Without a Clutch Coupling)

Aero Hot Water Heater

Burner	Firing Rate US gph	TI At the Standard Draft	At the Increased Draft	At the Reduced Draff
Beckett 3450 rpm	0.5	88	94	80
	0.75	83	90	70
	1.00	87	94	70
Aero 3450 rpm	0.5	75	88	69
	0.75	71	78	-16
	1.00	72	38	-113
Aero 1725 rpm	0.5	55	87	74
	0.75	77	92	14
	1.00	82	92	47
Anthes 1725	0.5	70	63	60
	0.75	76	87	57
	1.00	49	67	8
Terry 1725 rpm	0.5	66	77	63
	0.75	80	77	80
	1.00	74	78	54
Beckett 1725 rpm	0.5	70	69	50
	0.75	59	58	53
	1.00	1	77	65

TABLE A12

TRANSIENT INDEX

(Without a Clutch Coupling)

American Standard Hot Water Boiler

Burner	Firing Rate US gph	TI At the Standard Draft	TI At the Increased Draft	TI At the Reduced Draft
Beckett 3450 rpm	0.5	78	60	66
	0.75	83	86	57
	1.00	99	73	82
Aero 3450 rpm	0.5	60	82	66
	0.75	56	97	49
	1.00	43	58	23
Aero 1725 rpm	0.5	81	64	65
	0.75	79	73	33
	1.00	72	83	70
Anthes 1725 rpm	0.5	66	80	64
	0.75	70	85	47
	1.00	70	66	26
Terry 1725 rpm	0.5	56	69	55
	0.75	62	78	54
	1.00	78	79	-52
Beckett 1725 rpm	0.5	68	57	64
	0.75	83	80	56
	1.00	76	85	56

TABLE A13

STEADY RUNNING COMBUSTION PERFORMANCE

The Effect of Fuel Type

Test Furnace: American Standard Hot Water Boiler
Firing Rate: 1 US gph

Standard Draft Condition

Burner	Reference Fuel				Ottawa Valley No. 2 Oil			
	CO_2 %	CO ppm	NO lb/1000 lb Fuel	Smoke Number	CO_2 %	CO ppm	NO lb/1000 lb Fuel	Smoke Number
Beckett 3450 rpm	10.0	<20	3.0	0	13.0	<20	1.86	0
Aero 3450 rpm	10.8	<20	2.57	0	12.4	<20	1.30	0
Aero 1725 rpm	11.6	<20	2.11	<1	13.0	<20	1.63	0
Anthes 1725 rpm	10.6	<20	2.0	<1	11.7	20	1.05	<1
Terry 1725 rpm	9	<20	2.12	0	8.5	<20	1.28	1.5
Beckett S 1725 rpm	8.1	<20	1.62	0	7.9	<20	1.11	0

Burner	Evaluation Index	
	Reference Fuel	No. 2 Fuel Oil
Beckett 3450 rpm	74	87
Aero 3450 rpm	79	83
Aero 1725 rpm	78	88
Anthes 1725 rpm	80	82
Terry 1725 rpm	71	71
Beckett 1725 rpm	74	76