# FURNACE EFFICIENCY TESTING

## FINAL REPORT

by

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## INTRODUCTION

In Alaska, with its arctic and sub-arctic environment, much of the homeowner's fuel budget goes for space heating and domestic hot water. The rising cost of energy has added a great incentive for all fuel users to maximize the return on every fuel dollar. With these factors in mind the Department of Transportation and Public Facilities (DOT&PF) has undertaken a survey of home and small scale commercial heating units to determine typical operating efficiencies and what effect maintenance has on the performance of these units.

## DISCUSSION OF EFFICIENCY

There are several ways of evaluating the performance of a heating unit. Steady state efficiency is a measure of the burner performance during continuous operation, while the cycle efficiency includes information about the on-off cycling of the burner and indicates the fraction of useful steady state heat that is available during intermittent operation (McDonald et al., 1979). The overall efficiency is the product of the steady state efficiency and the cycle efficiency. During continuous operation, a fraction of the heat released by combustion of the fuel is lost in combustion products vented out the stack and as radiative and convective losses from the unit. Additional losses occur as the combustion chamber, boiler water and heat exchange surfaces cool between firings. These are called cycling losses.

Combustion efficiency, a steady state parameter, is the energy released in combustion divided by the maximum energy available in the fuel. Mathematically, it is the enthalpy of the products less the enthalpy of the reactants divided by the higher heating value of the fuel (Dyer and Maples, 1981). Combustion efficiency calculations assume all losses other than stack losses to be useful in meeting the heating requirements of the building. Hence the addition of a stack robber to capture some of the heat leaving in the exhaust gases will improve the combustion efficiency even though it does not affect the burning process.

Combustion efficiency was used as the measure of performance in this study. It can be determined from easily measured parameters using inexpensive test equipment readily available to furnace repairmen. No effort was made to determine the overall efficiency of the heating systems tested; once the combustion efficiency has been optimized by tuning the burner, the overall efficiency is fixed by the design and installation of the mechanical equipment.

Combustion efficiency is a function of the net stack temperature and the $CO_2$ concentration in the flue gas. Low stack temperatures and high $CO_2$ values give high efficiencies.

For a given firing rate, stack temperature is a direct measure of how well the heat exchanger is doing its job. As soot and scale build up on the transfer surfaces, the thermal conductivity decreases and more energy is lost up the stack. This causes an increase in stack temperature. Other factors can also affect stack temperature. Changing the firing rate will change the temperature accordingly. Also, since the rate of heat transfer is directly proportional to the temperature drop across the transfer surface, a boiler that has been cold started will have a lower exhaust temperature than it has when steady-state conditions are achieved.

$CO_2$ concentration is a measure of the amount of excess air in the combustion process. Maximum $CO_2$, and also maximum efficiency, occur when the air supplied is exactly that required to completely combust all of the fuel and no more (100% theoretical air, or 0% excess air). Reductions in efficiency occur much more quickly if deficient air is supplied rather than excess air (Dyer and Maples, 1981). For this reason and several others, the general rule is to provide excess air in any combustion process.

It would seem that tuning a burner is simply a matter of maximizing $CO_2$ and minimizing stack temperature. Unfortunately, the closer 100% theoretical air is approached, the more incomplete is the combustion that occurs in the flame. The result is unburned carbon in the exhaust. A layer of unburned carbon (soot) accumulates on the heat exchanger, reducing the thermal conductivity and lowering the efficiency. To minimize this problem a third parameter called smoke number is used in the tuning process. The smoke number is a 0 - 9 reference scale which allows a comparison, from time to time and burner to burner, of the amount of soot in the exhaust gas. A properly tuned burner will have as high a $CO_2$ number as possible while still maintaining a 0 - 1 smoke.

It is possible to calculate the combustion efficiency each time a furnace or boiler is tested, and Appendix B of McDonald et al (1979) is set up to take one step by step through the process. This calculation is usually not necessary, since that reference also contains combustion efficiency tables over a wide range of temperatures and percent $CO_2$ values for most common types of fuel. All that one must know are the net stack temperature, the $CO_2$ concentration, and the type of fuel. Furnace efficiency test kits from various manufacturers also contain condensed versions of the same information in nomograph form. The combustion efficiencies presented with the data were taken, in order of preference, from McDonald et al (1979), the Fire Efficiency Finder (a nomograph provided with the test kit from Bacharach Instruments Inc.), and calculations based on the data.

The economic benefits of improved combustion efficiency can be readily computed. Let us take for example, a hypothetical burner operating at a firing rate of 1 gph with a steady-state combustion efficiency of 70% and assume that, through tuning, the combustion efficiency is improved to 75% with the firing rate unchanged. This means that, prior to tuning, one gallon of fuel containing 135,000 Btu would produce 94,500 Btu of useful energy.

$$(135{,}000 \text{ Btu input} \times .70 = 94{,}500 \text{ Btu output})$$

After tuning, with the combustion efficiency at 75%, the same burner would only need to burn only .933 gallons of fuel to produce the same 94,500 Btu of useful energy as shown below:

$$\frac{94{,}500 \text{ Btu output}}{.75} = 126{,}000 \text{ Btu input}$$

$$\frac{126{,}000 \text{ Btu input}}{135{,}000 \text{ Btu/gal}} = .933 \text{ gal}$$

Since only 93.3% as much fuel is needed to produce the same amount of useful energy, that translates into a 6.7% savings or $6.70 on every $100 spent on fuel. Thus the cost of a cleanout and tuneup, typically $80 - $120, can be recovered in about one year if the improvement is at least 5% and the total fuel bill is around $2,000 per year.

## DESCRIPTION OF TEST EQUIPMENT

The net stack temperature ($T_{net} = T_{stack} - T_{air}$) and the composition of the exhaust gases provide a direct measure of the steady-state combustion efficiency. An oil burner combustion testing kit from Bacharach Instruments was used to determine the stack temperature, the $CO_2$ content in the exhaust gases, and the smoke number. A bi-metal thermometer with a range from 200°F to 1,000°F measured stack temperature. The $CO_2$ content was determined volumetrically with a graduated flask containing a potassium hydroxide absorbing solution. The smoke number was obtained with a hand suction pump which drew a known volume of gas through a filter and allowed the discoloration to be measured against a comparison chart. This type of test kit is commonly used as a diagnostic tool by furnace repairmen performing burner tuneups. In addition to use of the Bacharach kit, on-site grab samples of the furnace flue gas were taken with a Thomas pump and tedlar bags for further analysis in the laboratory.

An Infrared Industries combustion analyzer was used to determine the $CO_2$, carbon monoxide (CO) and oxygen ($O_2$) concentrations in the grab samples. This unit, which was provided by the University of Alaska-Fairbanks Mechanical Engineering Department, was installed and operated in one of the engineering labs on campus. The oxygen analyzer operates on a coulometric process whereby the oxygen in the sample is reduced in an electro-chemical cell with the resultant cell current proportional to the oxygen concentration. The CO - $CO_2$ analyzer is a nondispersive infrared measuring instrument. The sample stream is passed through a beam of infrared light and the CO and $CO_2$, both strong absorbers in the infrared region, reduce the beam strength. The amount of attenuation is then proportional to the concentration of CO and $CO_2$ in the sample.

# STUDY DESIGN AND TEST PROCEDURES

The initial phase of the study was to acquire some expertise in furnaces and learn to recognize the symptoms of their various operating and maintenance problems. Then a random sample of home heating units was tested to determine the combustion efficiency. Where warranted the units were cleaned or tuned by professional furnace repairmen and then retested. The furnaces at some of the DOT&PF maintenance camps in the Northern Region were also tested. The results were compiled and compared. Conclusions regarding typical operating efficiency, effect of maintenance, and potential for improvements in energy use were drawn.

Several days were spent accompanying Charles Deer and Bill Kegley of Deer's Heating Service as they repaired, cleaned and tuned an assortment of boilers around Fairbanks. This allowed observation of a wide variety of problems in furnaces and boilers as well as the remedial efforts necessary to solve them.

The testing procedure was divided into two parts; those measurements taken on site while the heating unit was operating and the analyses performed later in the lab.

A standard routine was developed for the on-site testing in order to minimize the time spent operating the unit. Prior to startup all pertinent information regarding the unit was recorded, i.e. make and model of heater, type, firing rate, etc. If there was not already a 1/4" hole in the stack somewhere just above the exhaust outlet on the unit, one was made with a punch. The unit was then fired, either by running a hot water faucet or turning up a thermostat somewhere in the building. While waiting for the temperature to stabilize, the smoke number was taken. The $CO_2$ content in the stack gas was determined with the Fyrite $CO_2$ indicator. At least three samples were taken for both smoke and $CO_2$. By then the unit had probably reached a stable operating temperature so the stack temperature was measured. Once the temperature was taken, the sample line from the pump was inserted into the stack and a sample transferred to a tedlar sample bag (20 liters was more than sufficient). During this process a 20 - 760°F asphalt thermometer was used to determine the ambient temperature. The asphalt thermometer also proved useful when a longer reach was needed to determine the stack temperature. Using the $CO_2$ value and $T_{net}$, the combustion efficiency was determined from the Bacherach Fire Finder slide rule. If it looked like tuning and/or cleaning would result in at least a 5% improvement in the combustion efficiency of a furnace, the owner was asked to arrange for the work to be done.

The grab samples were brought to the lab for further analysis using the Infrared analyzer. Prior to running the sample, proper operation of the Infrared equipment was verified with the four calibration gases ($CO_2$, $O_2$, CO, and zero nitrogen).

The Infrared analyzer was left operating continuously. In this mode, it had less tendency for it to drift than when shut down and restarted each day it was needed.

If the boiler was cleaned and retuned, an effort was made to be present during the work in order to observe what sort of problems existed with the unit. Usually a stack temperature was taken after cleaning, but prior to tuning, to determine the efficiency loss due to sooting alone.

## SUMMARY OF RESULTS

A total of 19 heating units of various types were tested. Of these, 10 were oil-fired hot water boilers, 5 were oil-fired forced air furnaces, 2 were oil-fired pot burners, and 2 were coal-fired hot water boilers. Nearly all of the hot water boilers were residential units, while most of the forced air furnaces were located at DOT&PF maintenance camps. The boilers could be operated by simply running the hot water, but the forced air units required turning up the heat. Most homeowners with forced air units were understandably reluctant to turn on the heat in the hot summer weather.

Where the results of the initial testing indicated the unit was out of tune or in need of cleaning, the owner was notified and the maintenance performed at owner expense by the individual of his choice. In one situation the tune-up was performed by DOT&PF personnel, and one unit was brushed out by DOT&PF personnel.

A summary of the testing data and results is given in Table I. A complete breakdown of the sampling results and comments pertinent to each test is listed in Appendix A. To help the reader understand the statistical breakdown of the data, Table I also includes a "statistics codes/comments" column showing where the various results were used.

The average combustion efficiency for all the units tested was 71.4% with a range from 42.0% to 83.6%.

The average efficiency of the gun-type oil fired units was 76.5% (14 units), with the boilers averaging 76.4% (8 units) and the furnaces averaging 76.6% (5 units ). The boiler at the Mary Siah Recreation Center was not included in these calculations, since it has two firing modes and the overall combustion efficiency would be some weighted average between the values obtained for each mode.

Two pot-type oil burners were tested. Unlike the gun-type burners which mix atomized fuel with a forced air draft, the pot-type burners rely on combustion heat to vaporize the fuel and natural convection for combustion air. This is much less efficient, resulting in less complete combustion and greater amounts of unburned carbon. The two units had combustion efficiencies of 43.2% and 42.0%, respectively.

Two identical coal-fired units were tested. These were automatic underfed, forced draft boilers. The combustion efficiencies were 62.2% and 66.7%.

Five of the units, all boilers, were cleaned and/or tuned and then retested. The minimum improvement was a 3% increase in a unit that was simply brushed out, while another unit achieved a 9.4% increase in efficiency through cleaning and tuning. Not only will that owner see a drop in her fuel bills but she can once again enjoy a long shower without running out of hot water. The average improvement was 4.4 % for cleaning only while cleaning and tuning netted an average improvement of 6.75%. Table II lists the results before and after maintenance on the five boilers.

## TABLE I
## TESTING RESULTS SUMMARY

| TEST NO. | LOCATION | $T_{net}$ (°F) | $CO_2$ (%) | EFF. (%) | STATISTICS CODES/COMMENTS |
|---|---|---|---|---|---|
| OIL-FIRED UNITS<br>Boilers | | | | | |
| 1 | Energy Bldg | 670 | 10.0 | 73.9 | A, B, C |
| 5 | Pederson | 760 | 8.8 | 71.4 | A, B, C |
| 8 | Kailing | 494 | 10.0 | 79.5 | A, B, C  T below stack robber |
| 9 | Kailing | 414 | -- | 82.0 | $T_{net}$ above stack robber |
| 10 | Mary Siah | 655 | 12.1 | 77.4 | High fire; TRIACTOR* on |
| 11 | Mary Siah | 655 | 11.8 | 77.2 | High fire; TRIACTOR off |
| 12 | Mary Siah | 440 | 11.8 | 82.8 | Low fire; TRIACTOR on |
| 13 | Mary Siah | 455 | 11.7 | 82.4 | Low fire; TRIACTOR off |
| 14 | Mary Siah | 660 | 12.4 | 77.5 | High fire; TRIACTOR off |
| 15 | Mary Siah | 445 | 12.0 | 82.8 | Low fire; TRIACTOR off |
| 17 | Voigt | 690 | 8.0 | 68.6 | A, B, C |
| 21 | Miller | 515 | 9.8 | 78.4 | A, B, C |
| 27 | Smith | 710 | 10.0 | 72.7 | A, B, C |
| 30 | Lowery | 535 | 11.8 | 80.3 | A, B, C |
| 31 | Zarling | 610 | 12.9 | 79.4 | A, B, C |
| 35 | Tok | 275 | 7.7 | 83.6 | A, B, C |
| Forced Air Furnaces | | | | | |
| 22 | Rezek | 615 | 9.0 | 73.8 | A, B, D |
| 33 | Birch Lake | 480 | 8.3 | 77.2 | A, B, D |
| 34 | Birch Lake | 685 | 13.2 | 77.8 | A, B, D |
| 36 | Gardiner Creek | 765 | 14.8 | 77.3 | A, B, D |
| 37 | Delta Jct | 585 | 10.2 | 77.0 | A, B, D |
| Pot Burners | | | | | |
| 19 | Durrenberger | 395 | 3.2 | 43.2 | A, E |
| 38 | Hegdal | 385 | 2.8 | 42.0 | A, E |
| COAL-FIRED UNITS<br>Boilers | | | | | |
| 16 | Griffin | 650 | 8.0 | 62.2 | A, F |
| 24 | Weaver | 775 | 10.3 | 66.7 | A, F |
| 25 | Weaver | 745 | | 67.7 | $T_{net}$ after raking the fire tubes |

TABLE I (Continued)

EFFICIENCY STATISTICS

| Statistics Code | Type of Equipment | No. of Units | Average Efficiency (%) |
|---|---|---|---|
| A | All unites tested | 18 | 71.4 |
| B | Gun-type oil burners | 14 | 76.5 |
| C | Oil boilers | 9 | 76.4 |
| D | Oil furnaces | 5 | 76.6 |
| E | Pot burners | 2 | 42.6 |
| F | Coal boilers | 2 | 64.5 |

* The main boiler at the Mary Siah Recreation Center is equipped with a TRIACTOR combustion improvement device manufactured by Thermics Corporation. All systems except for pool heat were shut down and the boiler operated in both high fire and low fire mode. Testing was performed with the TRIACTOR in operation and then disconnected. The boiler was tested again after three weeks of operation with the TRIACTOR disconnected. As the testing results indicate, the TRIACTOR made no discernible difference in the combustion efficiency measurements of the boiler.

## TABLE II
## CLEANING AND TUNING RESULTS SUMMARY

| TEST NO. | LOCATION | $T_{net}$ (°F) | $CO_2$ (%) | EFF. (%) | STATISTICS CODES/COMMENTS |
|---|---|---|---|---|---|
| 2 | Energy Bldg | 610 | 10.5 | 76.5 | I/Before cleaning |
| 3 | Energy Bldg | 495 | 10.0 | 79.6 | G/After cleaning |
| 4 | Energy Bldg | 515 | 11.2 | 80.0 | H/After tuning |
| 5 | Pederson | 675 | 8.8 | 71.4 | I/Before cleaning |
| 6 | Pederson | 530 | -- | 76.6 | G/After cleaning |
| 7 | Pederson | 455 | 8.8 | 79.3 | H, J/After tuning and reducing the nozzle size |
| 17 | Voigt | 690 | 8.0 | 68.6 | I/Before cleaning |
| 18 | Voigt | 450 | 8.0 | 78.0 | H, J/After cleaning and tuning |
| 27 | Smith | 710 | 10.0 | 72.7 | I/Before cleaning |
| 28 | Smith | 510 | -- | 78.9 | G/After cleaning |
| 29 | Smith | 510 | 9.9 | 78.9 | H, J/After tuning |
| 31 | Zarling | 610 | 12.9 | 79.4 | I/Before cleaning |
| 32 | Zarling | 490 | -- | 82.4 | G/After cleaning |

## EFFICIENCY STATISTICS

| Statistics Code | Description | No. Units | Average Efficiency (%) |
|---|---|---|---|
| I | Before Maintenance | 5 | 73.7 |
| G-I | Improvement After Cleaning | 4 | 4.4 (improvement) |
| H-I | Improvement After Cleaning and Tuning | 4 | 6.8 (improvement) |
| H | After maintenance | 4 | 79.7 |

# DISCUSSION OF RESULTS

Generally, the end result of most of the problems encountered in the heating units tested was soot accumulation on the heat transfer surfaces. The stack temperature will rise 40°F with each 1/64 inch of soot on the heat exchanger (Burkhardt, 1969) and each 40°F rise represents a drop of 1% in the combustion efficiency (Dyer and Maples, 1981).

Some of the causes of incomplete combustion which lead to a sooty fire include a worn or improperly sized nozzle and incorrect adjustment of the primary air. Dirt and lint accumulation, especially from clothes dryers located nearby, can also clog the blower fan and result in a sooty fire with a once properly tuned burner. These sorts of problems are readily identified and remedied by a competent furnace repairman during a routine tuneup of the burner. The unit is then tuned to produce a 0 - 1 smoke.

A furnace or boiler with a properly tuned burner will not accumulate soot on the heat exchange surfaces according to the furnace repair people questioned (Deer, Kegley). Examination of the units tested tended to confirm this view. The furnaces at the various DOT&PF maintenance camps are cleaned annually, usually in fall or early winter and tuned to a 0 - 1 smoke. None of them showed any indication of soot accumulation whatsoever after 6 - 8 months of operation. The Pederson boiler had a significant soot accumulation even though it had an initial smoke number of 0 - 1. The unit had been tuned several times in the last few years; however, there is no record of it ever having been cleaned so it is impossible to say when the sooting occurred. The Energy Center boiler and the Zarling boiler, both Weil McClains, each had 0 - 1 smoke and neither showed any evidence of soot accumulation when opened up for cleaning. The Zarling boiler had not been touched since its installation 5 years ago although the Energy Center unit had been cleaned the previous fall. Even though there was no black soot, both did contain a layer of fine gray-brown, ash-like material on the heat exchanger which did interfere with the heat transfer significantly.

The level of maintenance on the home heating units ranged from total neglect to annual tuneups, whereas the systems installed at the DOT&PF maintenance camps are cleaned and tuned every year. One result of this higher level of maintenance is that the average efficiency of the public facilities tested was about 3% greater than the average of the private residences with oil burning units (78.6% vs 75.3% respectively). If the post-maintenance efficiencies are included in figuring the residential average, the average performance is about equal (78.6% DOT&PF vs 78.9% home).

In general, it appears that annual tuneups and cleaning are essential for the most efficient operation of a furnace or boiler. The lack of soot accumulation in any of the DOT&PF furnaces after nearly one year of operation implies that annual brushouts are not necessary in properly tuned burners, i.e., those with a 0 - 1 smoke. The Kailing boiler was the only unit tested which had any record of past performance, so hard evidence about the time-wise degradation in burner performance is lacking. However, the tests on the Kailing boiler as well as the Zarling boiler tend to confirm the statements by the furnace repairmen that a tuned boiler will stay tuned for at least several years.

When only two parameters are used to determine the combustion efficiency it is important that the determination of those parameters be as accurate as possible. On the whole there was good agreement between the Bacharach $CO_2$ numbers and the Infrared $CO_2$ numbers. Occasional disagreement did occur, especially in units with unstable operation where an instantaneous value may vary widely from the results of a more integrated sample. This was the case with the Weaver coal boiler where the Bacharach kit indicated an 8.5% $CO_2$ concentration initially and a 10.0% $CO_2$ concentration after adjusting the primary air control. When the grab samples (each taken over a 5 minute period) were analyzed, both by the Infrared and the Bacharach methods, the results indicated the exact opposite, 10.3% $CO_2$ initially and 8.4% $CO_2$ after adjustment. It should be emphasized, however, that this unit fluctuated greatly and it required as many as 6 or 8 Bacharach $CO_2$ tests before any kind of consensus could be reached as to what to the $CO_2$ concentration might be. Generally, degradation of the absorbing solution in the Bacharach $CO_2$ tester is quickly noticed and the solution changed.

The other parameter, stack temperature, is a more subtle source of error. In a tradeoff of durability for accuracy, the manufacturers of the combustion analysis test kits use bi-metal thermometers instead of a more accurate mercury filled glass thermometer. The bi-metal thermometers are generally not replaced unless they are physically broken or so grossly inaccurate as to be obvious to anyone. Unless it is occasionally checked against some other reference, the user will never be aware of any gradual degradation in performance. One bi-metal thermometer encountered during the testing program was approximately 80°F low in the range of typical stack temperatures. "No wonder I've been getting such good efficiencies lately," was the repairman's comment when the error was discovered.

## CONCLUSIONS AND RECOMMENDATIONS

Combustion efficiency is a reliable means for measuring the relative performance of home and small scale commercial heating units. It does not, however, give any indication of the seasonal efficiency of the heating system. Seasonal efficiency is tied in with design factors that are beyond the scope of this study.

The equipment necessary to determine combustion efficiency is simple to use and readily available. Such equipment is widely used by people in the furnace repair industry when tuning a burner. In order to minimize the possibility of error in determining the combustion efficiency the fluid in the $CO_2$ monitor should be changed regularly and the bi-metal stack thermometer should be checked against a known temperature source or another thermometer at least annually.

Although the heating units at the public facilities had an average efficiency 3% greater than the average of the units in private residences (78.6% vs 75.3% respectively) it was slightly less than the average final efficiency of the five home units which were cleaned and tuned (78.6% DOT&PF vs 79.7% private).

As the results of the testing indicate, a major improvement in the combustion efficiency of many home heating units is possible using the expertise of local furnace repairmen. Much of the gain in improvement came from cleaning the heat transfer surfaces. A properly tuned unit with a fouled heat exchanger will still continue to operate at a lower level of performance due to the reduced ability to transfer heat. The lack of any soot accumulation in units with properly tuned burners implies that a furnace or boiler that has been cleaned and tuned will continue to operate with a high combustion efficiency for several years.

The sample of furnaces tested at public facilities revealed little or no room for improvement in combustion efficiency due to the high level of maintenance currently performed. The absence of any soot accumulation in any of the units suggests that cleaning the fire box, heat exchanger, and stack is probably not necessary on an annual basis.

Lack of any record of past performance on nearly all of the units made it difficult to evaluate the rate of degradation of the combustion efficiency or to project what sort of improvement could be expected from maintenance efforts. Many times the furnace repairman would have to second guess the logic behind the "improvements" found on some of the boilers. This situation could be easily eliminated if repairmen would note the stack temperature, $CO_2$ number, smoke number, combustion efficiency, nozzle size, and any comments deemed important on a card or sheet of paper and leave it with each furnace they worked on. In this manner future repairmen would have a reference guide of the performance others were able to achieve from the unit as well as a history of problems it might have had.

Almost any change in the performance of a heating unit will result in a change in the stack temperature. With this in mind a maintenance man or homeowner could monitor the performance of his heating unit by simply measuring the stack temperature regularly. Using the rule of thumb that a rise of 40°F represents a drop of 1% in efficiency, it would be possible to perform maintenance based on need. Bi-metal thermometers with a range adequate for the job can be had for as little as $20 from various equipment suppliers, although the thermometers which come with the combustion test kits are more like $40.

# IMPLEMENTATION (Prepared by the Department of Transportation and Public Facilities)

The results of this research show that little, if any, improvement can be made in furnace efficiency in DOT&PF facilities by increased maintenance. Furnaces tested in Department maintenance camps had steady state efficiencies in the 77 to 84% range, which is excellent.

Maintenance men in public facilities can use these figures as a benchmark to guide them in maintaining heating equipment. Department engineers can use this information to aid them in deciding when a heating system needs to be replaced and what type of replacement equipment to specify.

This report will be widely distributed to the general public in an effort to disseminate this information where it will have the most benefit. A large number of copies will be printed to supply requests for the report. Furnace efficiency will also be the subject of a Research Newsletter.

The information in this report is being used in a more comprehensive report entitled "Heat Generation System." This report will be published as soon as permission is received from several manufacturers to reprint information supplied by them.

# REFERENCES

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# APPENDIX A
# TEST RESULTS

## Key to Abbreviations

k = 1000

Btu = British thermal unit

$CO_2$ = carbon dioxide concentration in the flue gas as measured by the Bacharach Test kit (%)

$CO_2$ = (Infrared) = carbon dioxide concentration in the flue gas as measured by the Infrared Analyzer (%)

CO = (Infrared) = carbon monoxide concentration in the flue gas as measured by the Infrared Analyzer (%)

$O_2$ = (Infrared) = oxygen concentration in the flue gas as measured by the Infrared Analyzer (%)

Eff = combustion efficiency (%)

gph = gallons per hour

hr = hour

Smoke = smoke number as measured by the Bacharach Test kit

$T_a$ = temperature of the air in the vicinity of the furnace (°F)

$T_s$ = temperature of the stack gases (°F) $T_{net}$ = $T_s - T_a$ (°F)

$T_{net}$ = $T_s - T_a$ (°F)

# TEST RESULTS

Location

ENERGY BUILDING

Model and Type

Weil McClain 366E-WT series 3
109k Btu/hr output 0.95 gph fuel
boiler

## Test Data

| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | (Infrared) $CO_2$ | (Infrared) $O_2$ | (Infrared) CO | Eff |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6/13/83 | 750 | 80 | 670 | -- | 10.0 | 8.5 | 10.7 | 0.00 | 73.9 |
| 2 | 6/15/83 | 670 | 60 | 610 | 0 | 10.5 | 10.5 | 7.4 | 0.00 | 76.5 |
| 3 | 7/7/83 | 570 | 75 | 495 | 0-1 | 9.5 | 10.0 | 7.4 | 0.00 | 79.6 |
| 4 | 7/7/83 | 590 | 75 | 515 | 0 | 11.5 | 11.2 | 5.8 | 0.00 | 80.0 |

## Comments

Test #1 - The Infrared results are incorrect because the Fyrite indicated 9.5% $CO_2$ in the sample taken for infrared analysis. The boiler was on line when tested.

Test #2 - The boiler had been shut down for the summer since the last visit. The lower stack temperature and greater efficiency is probably due to having cold water in the unit.

Test #3 - The combustion chamber and heat exchanger were brushed and vacuumed. There was no evidence of sooting; however, the heat transfer surface was covered with a coating of fine grey-brown ash-like material which brushed off easily.

Test #4 - The primary air was adjusted by DOT&PF to reduce the excess air while still maintaining a 0 - 1 smoke.

| Location | Model and Type |
|---|---|
| KAILING | National U.S. 70-146 series 70<br>127k Btu/hr output 1.35 gph fuel<br>boiler |

Test Data

|  |  |  |  |  |  |  | (Infrared) |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | $CO_2$ | $O_2$ | CO | Eff |
| 8 | 6/16/83 | 560 | 66 | 494 | 0-1 | 10.0 | 10.0 | 9.0 | 0.00 | 79.5 |
| 9 | 6/16/83 | 480 | 66 | 414 | -- | -- | -- | -- | -- | 82.0 |

Comments

Test #8 - The unit was tuned one year ago (6/16/82) and the results posted next to the boiler. The $CO_2$ and smoke number had not changed over the year, however the $T_s$ was 650 F. The owner indicated he had brushed and vacuumed the heat exchanger in Sept. 82 which probably accounts for the reduced stack temperature.

Test #9 - This unit was equipped with a stack robber and this stack temperature was taken above it with the fan operating.

---

| Location | Model and Type |
|---|---|
| PEDERSON | American Standard Products A-34-P series 1B-J1<br>136k Btu/hr output 1.35 gph fuel<br>boiler |

## Test Data

| | | | | | | | (Infrared) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | $CO_2$ | $O_2$ | CO | Eff |
| 5 | 8/3/83 | 760 | 85 | 675 | 0-1 | 9.5 | 8.8 | 9.2 | 0.01 | 71.4 |
| 6 | 8/3/83 | 615 | 85 | 530 | -- | -- | -- | -- | -- | 76.6 |
| 7 | 8/3/83 | 540 | 85 | 455 | 0-1 | 9.5 | 8.8 | 9.1 | 0.01 | 79.3 |

## Comments

Test #5 - These results are prior to cleaning and tuning

Test #6 - The unit was fired long enough to get a stack temperature after it had been cleaned.

Test #7 - During tuning the nozzle was reduced to drop the firing rate down to 1.1 gph which accounts for the additional 75 drop in the exhaust temperature.

---

| Location | Model and Type |
|---|---|
| MARY SIAH REC. CENTER | Weil McClain WRL 890905 size BL-686-SW<br>1160k Btu/hr output 10.2 gph fuel<br>boiler |

## Test Data

| | | | | | | (Infrared) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | $CO_2$ | $O_2$ | CO | Eff |
| 10 | 6/24/83 | 745 | 90 | 655 | 0-1 | 12.0 | 12.1 | 4.9 | 0.01 | 77.4 |
| 11 | 6/24/83 | 745 | 90 | 655 | 0 | 12.0 | 11.8 | 5.2 | 0.01 | 77.2 |
| 12 | 6/24/83 | 530 | 90 | 440 | 4 | 12.0 | 11.8 | 5.2 | 0.04 | 82.8 |
| 13 | 6/24/83 | 545 | 90 | 455 | 3 | 12.0 | 11.7 | 5.3 | 0.04 | 82.4 |
| 14 | 7/18/83 | 745 | 85 | 660 | 0-1 | 12.5 | 12.4 | 5.1 | 0.00 | 77.5 |
| 15 | 7/18/83 | 530 | 85 | 445 | 4 | 12.0 | 12.0 | 5.4 | 0.03 | 82.8 |

## Comments

This boiler is equipped with a TRIACTOR ionization unit to improve the combustion efficiency. During testing all systems were shut down except pool heat and the unit tested in high fire and low fire modes with the TRIACTOR on and off.

Test #10 - High fire with the TRIACTOR on.

Test #11 - High fire with the TRIACTOR off.

Test #12 - Low fire with the TRIACTOR on.

Test #13 - Low fire with the TRIACTOR off.

Test #14 - High fire with the TRIACTOR off for the preceding three weeks.

Test #15 - Low fire with the TRIACTOR off for the preceding weeks.

| Location | Model and Type |
|---|---|
| GRIFFIN | Prills WTB-18-200<br>210k Btu/hr output<br>coal fired boiler |

**Test Data**

|  |  |  |  |  |  |  | (Infrared) |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | $CO_2$ | $O_2$ | CO | Eff |
| 16 | 6/28/83 | 740 | 90 | 650 | >9 | 8.0 | 4.7 | 14.8 | 0.09 | 62.2 |

**Comments**

Test #16 - This is an auger fed coal boiler with forced draft during firing and natural draft during nonfiring periods. The system was "tuned" by reducing the combustion air until unburned coal began appearing in the ash. The unit stopped firing while the grab sample was being taken so the sample was contaminated with air. Fuel consumption was estimated at 1 ton per month during the summer months when the boiler is used for domestic hot water only and 1 ton per week when heating the house at -40 F.

---

| Location | Model and Type |
|---|---|
| VOIGT | National U.S. Sunray 4 Automatic Heating Boiler<br>4-19A-0/0P 100.5k Btu/hr output 1.3 gph fuel<br>boiler |

## Test Data

| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | $CO_2$ (Infrared) | $O_2$ (Infrared) | CO | Eff |
|---|---|---|---|---|---|---|---|---|---|---|
| 17 | 6/29/83 | 770 | 80 | 690 | 6-7 | 8.0 | 8.0 | 10.4 | 0.07 | 68.6 |
| 18 | 6/30/83 | 540 | 90 | 450 | 1 | 9.5 | 8.0 | 10.5 | 0.01 | 80.0 |

## Comments

Test #17 - These results are prior to cleaning and tuning. The owner complained of insufficient hot water.

Test #18 - The unit was cleaned and tuned. Approximately 1/4" of soot was brushed off the heat exchanger. The fan blades on the air blower were plugged with lint and dirt. The nozzle was undersized for this burner, however when the correct nozzle was installed there was a positive pressure in the combustion chamber and exhaust was blowing back into the room. Upon examination of the stack it was found that the chimney was almost completely blocked with old cement and a large accumulation of soot. Once the blockage was cleared the stack could handle the additional exhaust without any problem. Evidently as the soot accumulated, previous repairmen simply reduced the firing rate to maintain a negative draft. The new firing rate is 1 gph, up from .8 gph.

---

| Location | Model and Type |
|---|---|
| DURRENBERGER | Perfection 872L<br>.095 - .33 gph fuel<br>pot burner test data |

Test Data

| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | (Infrared)<br>$CO_2$ | $O_2$ | CO | Eff |
|---|---|---|---|---|---|---|---|---|---|---|
| 19 | 6/29/83 | 460 | 65 | 395 | 7 | 3.0 | 3.2 | 15.4 | 0.03 | 43.2 |
| 20 | 6/29/83 | 480 | 65 | 415 | 7 | 3.0 | -- | -- | -- | -- |

Comments

Test #19 and 20 - The burner pot was brushed out between tests to remove any soot clinging to the walls and plugging the air holes.

---

| Location | Model and Type |
|---|---|
| MILLER | Sears 229-94136 series T62<br>139.1k Btu/hr output 1.65 gph fuel |

Test Data

| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | (Infrared)<br>$CO_2$ | $O_2$ | CO | Eff |
|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 7/1/83 | 600 | 85 | 515 | 6 | 10.0 | 9.8 | 7.9 | 0.01 | 78.4 |

## Comments

Test #21 - The unit blows soot during start up. Soot remover is used periodically in the fuel. The owner replaces the nozzle annually and cleans the stack. The heat exchange surface was cleaned last fall. Tuning is done by looking at the flame as the air is adjusted. At the time of the testing an effort was made to reduce the smoke number; however, as the smoke went down so did the $CO_2$ so the unit was left with a 10% $CO_2$ and a number 5 smoke. The nozzle is probably not the one specified for the burner.

---

| Location | Model and Type |
|---|---|
| REZEK | Rheem Mfg. 4025-120ED<br>120k Btu/hr output 1.1 gph fuel<br>forced air test data |

## Test Data

| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | (Infrared)<br>$CO_2$ | $O_2$ | CO | Eff |
|---|---|---|---|---|---|---|---|---|---|---|
| 22 | 7/6/83 | 700 | 85 | 615 | 0-1 | 9.0 | 8.1 | 10.3 | 0.00 | 73.8 |
| 23 | 7/6/83 | -- | -- | -- | 0-1 | 9.5 | -- | -- | -- | 74.5 |

## Comments

Test #22 and 23 - Although the unit had not been cleaned in over three years the combustion chamber looked clean and there was no soot accumulation in the stack. The primary air was adjusted to try and improve the performance between tests.

| Location | Model and Type |
|---|---|
| WEAVER | Prills WTB-18-200<br>210k Btu/hr output<br>coal fired boiler test data |

## Test Data

| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | (Infrared)<br>$CO_2$ | $O_2$ | CO | Eff |
|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 7/25/83 | 855 | 80 | 775 | >9 | 8.5 | 10.3 | 10.6 | 0.17 | -- |
| 25 | 7/25/83 | 825 | 80 | 745 | -- | -- | -- | -- | -- | -- |
| 26 | 7/25/83 | 770 | 80 | 690 | 8 | 10.0 | 8.4 | 12.5 | 0.10 | 60.1 |

## Comments

Test #24 - The owner had the primary air shut down almost completely and the temperature would oscillate from 830°F to 800°F as the unit "breathed". The $CO_2$ numbers were equally unstable.

Test #25 - The fire tubes were raked of accumulated soot and a new stack temperature taken.

Test #26 - The primary air adjustment was opened and $CO_2$ numbers taken. Initially the $CO_2$ jumped to 15% and gradually dropped to 8%. The air was adjusted until it seemed to stabilize at 10%, however the results of the grab sample indicate otherwise. The owner estimated that about 1,500 lbs. of coal had been consumed since May to provide domestic hot water. During the winter when it also heats the house, coal consumption goes up to 1 ton per week at -40°F.

| Location | Model and Type |
|---|---|
| SMITH | American Standard APT165 series 1BJ1<br>143.5k Btu/hr input 1.6 gph fuel<br>boiler |

### Test Data

|  |  |  |  |  |  |  | (Infrared) |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | $CO_2$ | $O_2$ | CO | Eff |
| 27 | 7/26/83 | 785 | 75 | 710 | 3 | 11.0 | 10.0 | 8.3 | 0.00 | 72.7 |
| 28 | 8/4/83 | 570 | 60 | 510 | -- | -- | -- | -- | -- | 78.9 |
| 29 | 8/4/83 | 570 | 60 | 510 | 0-1 | 10.0 | 9.9 | 7.3 | 0.00 | 78.9 |

### Comments

Test #27 - Results prior to cleaning and tuning.

Test #28 - The unit was fired long enough to get a stack temperature after cleaning. There was a fine coating of soot on the heat exchange surfaces.

Test #29 - The nozzle was replaced with another of the same type and size and the air adjusted to give a 0 - 1 smoke.

---

| Location | Model and Type |
|---|---|
| LOWERY | Crane 70-146<br>127k Btu/hr output 1.35 gph fuel<br>boiler |

Test Data

| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | $CO_2$ (Infrared) | $O_2$ (Infrared) | CO | Eff |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 7/26/83 | 610 | 75 | 535 | 0-1 | 12.0 | 11.8 | 6.0 | 0.01 | 80.3 |

Comments

Test #30 - The owner felt this unit had serious problems and was considering replacing it. It was poorly installed with the access plate to the heat exchanger located against a wall. Since cleaning is virtually impossible the owners have the burner tuned annually. The combustion chamber looked very clean and the net stack temperature would indicate little or no soot in the heat exchanger. Considering the performance of the unit there was no apparent justification to warrant replacement.

---

| Location | Model and Type |
|---|---|
| ZARLING | Weil McClain P-466-E-WT series 3<br>120k Btu/hr output 1.25 gph fuel<br>boiler |

Test Data

| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | $CO_2$ (Infrared) | $O_2$ (Infrared) | CO | Eff |
|---|---|---|---|---|---|---|---|---|---|---|
| 31 | 7/26/83 | 680 | 70 | 610 | 1 | 12.0 | 12.9 | 4.6 | 0.01 | 79.4 |
| 32 | 7/26/83 | 560 | 70 | 490 | -- | -- | -- | -- | -- | 82.4 |

## Comments

Test #31 - Five years ago the owner installed this unit as it came from the factory. The primary air was adjusted back and forth, however, when the appearance of the flame did not seem to change the adjustment was just left in the middle. Since installation, there has been no service or maintenance performed on the unit.

Test #32 - The access plate to the heat exchanger was removed and the insides brushed out. There was 1/8 to 1/4 " of fine, dry, light brown, ash-like material coating the surfaces which brushed off easily. The ash was left in the bottom of the combustion chamber where it fell. No effort was made to tune the burner.

---

| Location | Model and Type |
|---|---|
| BIRCH LAKE<br>MAINTENANCE CAMP | Powrmatic Inc. CA45<br>430k Btu/hr output 4.0 gph fuel<br>forced air |

## Test Data

|  |  |  |  |  |  |  | (Infrared) |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | $CO_2$ | $O_2$ | CO | Eff |
| 33 | 7/19/83 | 550 | 70 | 480 | 1 | 8.0 | 8.3 | 10.4 | 0.01 | 77.2 |

Comments

Test #33 - This unit has a draft inducing blower in the stack. The overfire draft was much greater than the .25 " maximum on the test meter. Although the primary air controls were closed nearly all the way down the $CO_2$ number and the high draft imply that there is probably a great deal of tramp excess air being sucked in. There was no evidence of any soot accumulation in the combustion chamber.

---

| Location | Model and Type |
|---|---|
| BIRCH LAKE<br>MAINTENANCE CAMP | Dravo Hastings P-25-LO<br>250k Btu/hr output 3 gph fuel |

Test Data

|  |  |  |  |  |  |  | (Infrared) |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | $CO_2$ | $O_2$ | CO | Eff |
| 34 | 7/19/83 | 750 | 65 | 685 | 1-2 | 13.5 | -- | -- | -- | 77.8 |

Comments

Test #34 - There was no evidence of any soot accumulation in the combustion chamber. No grab sample was taken.

---

| Location | Model and Type |
|---|---|
| TOK MAINTENANCE CAMP | Kewanee Boiler KFRO-2-10<br>22 - 33 gph fuel |

Test Data

| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | (Infrared)<br>$CO_2$ | $O_2$ | CO | Eff |
|---|---|---|---|---|---|---|---|---|---|---|
| 34 | 7/20/83 | 340 | 65 | 275 | 0-1 | 8.0 | 7.7 | 11.2 | 0.01 | 83.6 |

Comments

Test #34 - This old boiler has an automatic control system on the primary air, however the controls never worked properly so the louvers were adjusted by hand "until the flame looked right" and the controls locked in place. No $CO_2$ or smoke number was ever taken during this process and the air adjustment has not been touched since. The fire tubes and combustion chamber are cleaned annually and the burner cleaned as often as once a week during the winter.

---

| Location | Model and Type |
|---|---|
| GARDINER CREEK<br>MAINTENANCE CAMP | Dravo Hastings P-25-LO<br>250k Btu/hr output 3 gph fuel<br>forced air |

Test Data

| | | | | | | | (Infrared) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | $CO_2$ | $O_2$ | CO | Eff |
| 36 | 7/19/83 | 825 | 60 | 765 | 1 | 14.5 | 14.8 | 1.84 | 0.04 | 77.3 |

Comments

Test #36 - This unit was operating at less than 10% excess air with no sooting whatsoever in the combustion chamber or heat exchange tubes. Bringing the stack temperature down a couple of hundred degrees would improve the efficiency 5%.

---

| Location | Model and Type |
|---|---|
| DELTA JUNCTION<br>MAINTENANCE CAMP | Dravo Hastings P-25-LO<br>250k Btu/hr output 3 gph fuel<br>forced air |

Test Data

| | | | | | | | (Infrared) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | $CO_2$ | $O_2$ | CO | Eff |
| 37 | 7/20/83 | 655 | 70 | 585 | 1 | 11.0 | 10.2 | 7.9 | 0.01 | 77.0 |

Comments

Test #37 - No evidence of sooting in either the combustion chamber or the exchange tubes.

| Location | Model and Type |
|---|---|
| HEGDAL | Preway DVM 100A<br>72k Btu/hr output<br>pot burner |

Test Data

| # | Date | $T_s$ | $T_a$ | $T_{net}$ | Smoke | $CO_2$ | (Infrared) $CO_2$ | $O_2$ | CO | Eff |
|---|---|---|---|---|---|---|---|---|---|---|
| 38 | 8/10/83 | 450 | 65 | 385 | 3 | 3.0 | 2.8 | 14.9 | 0.06 | 42.0 |

Comments

Test #38 - Although this was a much larger unit than the other pot burner tested, it was comparable in performance.