EXTENDED USE OF PLENUM HEATERS ON OIL-FIRED HEATING SYSTEMS: IMPLICATIONS FOR CHIMNEY INTEGRITY

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ABSTRACT

Chimney deterioration may increase with increased plenum heater use. If run with a lower outside temperature set-point, moist house air may flow up the chimney, condense and migrate into the mortar, causing deterioration. In the worst case, the interior of the chimney might collapse and cause flue blockage. This may occur in chimneys that are in good condition; defective chimneys, of which there are a large number, would be even more prone to this problem and should be repaired before a plenum heater is installed. A more severe problem may exist with a different type of control strategy - a two-stage thermostat operation throughout the winter. This may result in continuing condensing conditions when the oil furnace is firing on a reduced cycle length in cold ambient temperatures. Under such conditions, rapid chimney deterioration is possible. To minimize chimney problems, the oil furnace should be run whenever heat is required during a fixed time period, say 1600 to 1900 hrs, each day of the heating season, to dry out the chimney regularly, while also operating with a low outside set-point the rest of the time. This might also even have an electrical demand benefit.

INTRODUCTION

Concern has been expressed about the ability of existing chimneys to withstand the changing operating conditions which would occur when plenum heaters are installed in conjunction with existing oil furnaces, as part of the COSP program, or some other incentive program sponsored by the electric utilities.

With the plenum heater running, the oil furnace does not run with the same operating frequency as before, and the potential for chimney problems is increased.

Strategies for Operating the Plenum Heater

1. Have the plenum heater operate down to a specific outdoor temperature, below which the oil furnace operates. For the units sold by some oil companies, this temperature is set to -2^{o}C, although it can be reset by the user to any other temperature.

2. Have the plenum heater operate on a two-stage thermostat. If the inside temperature falls below a certain level, the oil furnace will run to bring the temperature back up and then the plenum heater will come on again. This type of control is the popular one with wood-oil furnaces.

3. Have the oil furnace preprogrammed to run a certain amount each day. This could either be a fixed amount of furnace operational time, or the varying furnace time required to supply all the heat needed for a fixed time frame each day.

WHAT ARE THE PROBLEMS?

Effect of Furnace Cycle Length

With the oil furnace running at shorter cycle lengths, it has been argued that the furnace efficiency is much lower than if the furnace runs longer. To some degree, this is borne out by the field trials CCRL has carried out (Reference 1) whereby, with decreased firing rate, the fuel savings increased with decreasing outside temperature. The reverse was found with positive chimney dampers, where the savings were greatest in the mildest weather and got less and less as the outside temperaure fell.

The increased efficiency with increased cycle length has to do with the heat exchange system becoming more and more in equilibrium. From the time that the furnace comes on, it takes an average of at least ten minutes until the furnace is in equilibrium and the flue gas temperature is stabilized. Until then, the temperature is gradually climbing. Typical flue gas temperatures at this point range from $175^{\circ}C$ to $400^{\circ}C$, with an average of somewhere around $300^{\circ}C$ (Reference 2).

Problems in chimneys may be accelerated by this reduction in firing rate, now accepted as an energy conservation practice, recogizing the fact that furnaces are generally greatly oversized for home heat demands (Reference 3). This practice will definitely result in lower steady state flue gas temperatures. It is not so clear that the net effect on chimneys will be to lower the average flue gas temperature in the stack. With increased furnace on-time, leaving the masonary less time to cool down, the average surface temperature (the dominant factor in condensation) may even be increased.

Dilution Effect of the Barometric Damper

To complicate matters further, there is the dilution device - the barometric damper - which feeds room air into the flue pipe in such a way as to hold a constant draft on the burner, isolating the burner from outside pressure fluctuations. The amount of dilution air admitted varies dramatically from one installation to the next, and with different weather conditions. The effect is to lower the flue gas temperature, but to a non-predictable level.

Figures 1, 2 and 3 show field test results of real time changes in flue gas temperature and carbon dioxide (CO_2) levels before and after the barometric damper in three representative homes: A, B and C, respectively. The excess air level, as measured by CO2, stabilizes rapidly, generally within the first two minutes; however, the flue gas temperature before dilution takes a much longer time to reach equilibrium. In the case of House A, equilibrium was not reached even after ten minutes of furnace operation. The temperature after dilution stabilizes slightly more rapidly.

The excess air level before dilution is in the 90% range for all three houses, typical of conventional (non-flame retention head) burners. On the other hand, excess air after dilution ranges from 270% for House B to 860% for House C. The chimney base temperatures decrease in a similar fashion. For House B, the temperature after dilution falls by 48%. For House C, the decrease is 71%. Flue gas water dewpoints for Houses A, B and C are $14^{\circ}C$, $28^{\circ}C$ and $11^{\circ}C$, respectively.

Potential for Condensation during Oil Furnace Operation

It is difficult to predict what the likelihood of flue gas condensation will be in any installation while the oil furnace is operating, without actual measurement of the dilution effect, due to the unpredictable nature of the dilution device and its effect on the water dewpoint of the flue gas. Figure 4 presents field test results from a number of homes where dewpoint is plotted against furnace exit temperature. No correlation is readily visible, with the highest (40°C) and the lowest (11°C) both occuring at furnace exit temperatures in the range of 270°C.

Two major driving forces for condensation in a system are the dewpoint of the gas stream and the inside surface temperature on the conduit through which the gas is passing. To determine the former, measurement should be made of the flue gas temperature and the excess air (by CO_2 or O_2), after the dilution device.

Effect of Shortened Furnace Cycles

The cycle length in condensing gas furnaces has been shown to have a major effect on the amount of water condensed (Reference 4). The shorter the cycle, the colder the surface temperatures and the cooler the flue gas temperature, both factors promoting condensation.

The same can be considered true for chimneys, if the furnace runs only for a short period of time. For a prefabricated metal chimney, response to flue gas temperature is quite rapid (Reference 5). It is still possible to consider conditions during the colder periods of the winter in installations where the chimney is on an outside wall when the chimney would not warm up on short furnace cycles and continued condensation during short furnace cycles could occur. Since this condensate is acidic (Reference 6), there is the definite chance of corrosion and subsequent degradation of the liner, with potentially catastrophic results (Reference 7).

In masonary chimneys, particularly outside installations, the range of conditions where short furnace cycles result in a continuously condensing mode is extended, primarily because masonary takes a longer time to heat up than metal. If the furnace cycle is too short and/or the outside temperature is too cold, with the time significantly extended between subsequent furnace cycles, the chimney may never warm up. Chimney failure is a definite possibility, not so much due to corrosion, but rather to the penetration of condensed flue water into the mortar, with the subsequent freezing and thawing. Symptoms of problems would be similar to that described below for off-cycle moisture penetration, with the added possible indicator of yellowish staining on the outside of the chimney, coming from the sulphur in the fuel. Condensate running out the furnace cleanout door is another danger sign.

Operation of the plenum heater with a two-stage thermostat is a significant change to operating conditions of the oil furnace which could well take installations which are now functioning adequately and move them into regimes where the oil furnace runs only for short bursts with extended off-cycle times in cold ambients - just the conditions where condensation and degradation can occur.

Effect of Prolonged (Weeks) Oil Furnace Off-Cycle Operation

As houses are being made tighter, and with air change rates decreasing dramatically with increased use of insulation, weatherstripping and caulking, moisture levels in existing houses are on the increase. This has long been recognized as a potential problem with the house structure in electrically heated houses, such as the Gold Medallion type built in Ontario in the late 1960's. These higher levels of moisture can result in condensation in the structure or even in the flue venting system, while the combustion appliance is not operating. In the latter case, it could result in long term corrosion, spalling, deterioration and even internal blockage. A potential catastophic effect from short term ice blockage of the flue is possible, but unlikely.

There is increasing evidence of problems with fireplace chimneys, even in those houses where the fireplace is used little, if at all. This problem is accentuated with tight housing, where moisture levels in the house become fairly high. Air escaping up the cool chimney of the fireplace is fairly moist and condenses on the inside walls. The moisture then can migrate into the masonary and cause spalling of the brick and motar as well as deterioration of the tile liner.

Defects with Existing Masonary Chimneys

As well, similar sorts of problems have occured in the deterioration of masonary chimneys in existing homes with oil or gas furnaces and no plenum heaters. In part, these can be traced to poor installation practice when the chimney was constructed (points 1,2,3,4), or in misplaced guidelines by regulatory agencies (point 5), below:

(1) Lack of tile liner.

(2) Incomplete tile liner. (eg. top and bottom sections installed to satisfy inspectors, but nothing in between.)

(3) Misalligned or cracked tiles, such that flue gas is thrown into the masonary.

(4) Non-continuous connection of the flue pipe and chimney liner.

(5) Changing fuel from oil to gas, the latter having twice the moisture content in the flue gas, with a consequently higher dewpoint and generally lower flue gas temperature, both of which promote significantly increased condensation in the venting system. In the Western Provinces, metal liners have long been required in outside masonary chimneys to increase flue gas velocity and reduce temperature drop. This was only recognized recently as a problem in Ontario, primarily after the rapid deterioration after conversion to gas of a large number of masonary chimneys in a suburb of Ottawa.

Simple indications of deterioration in masonary chimneys are:

(1) deterioration of the exposed tile at the top of the chimney.

(2) efflorescence (whitening) of the outside of the brick.

(3) spalling of the brick and mortar.

(4) tile segments at cleanout door.

(5) yellowish staining on outside of chimney.

(6) Significant water runout at chimney clean-out door.

Other potential problems are shown in Figure 5.

Problems may also occur with prefabricated metal chimneys, in terms of condensation, corrosion or freezing, but masonary chimneys should offer the more severe conditions to plenum heater installations.

POTENTIAL R&D TO DETERMINE PROBLEMS & SOLUTIONS FOR PLENUM HEATER INSTALLATIONS

(1) Use electrically heated homes with fireplaces as a surrogate example of what can happen to masonary chimneys in tight housing, by carrying out a survey. One potential location could be Trend Village in Ottawa, begun as an all-electric subdivision, but with oil and gas at the latter part of construction, although similar home construction has been used throughout.

(2) Examine the condition of a number of chimneys in an area where plenum heater conversion has been intensive, for obvious signs of deterioration, when compared to other houses in the same area which do not have plenum heaters, particularly looking for the characteristic yellowish stain.

(3) Study inside surface temperature response of masonary chimneys on a cold outside wall, to measure the effect of varying furnace cycle length on the amount an period of condensation.

(4) Measure the internal surface temperatures of an outside masonary chimney for normal and reduced firing rates, and for changes in furnace cycling length.

(5) Determine, if necessary, an effective means of lining an existing masonary chimney to ensure good performance. This would likely require a stainless steel liner, possibly with vermiculite as insulation, a good seal on top and a positive connection to the furnace flue on the bottom.

(6) Carry out a short experimental program to determine what might be the best way to run an oil furnace when connected with a plenum heater, in order to maximize use of electricity, without experiencing venting system degradation, or at least more deterioration than could normally be expected if only the existing oil system was used. Likely the most satisfactory system would be one that would allow a certain amount of oil furnace use every day, as the sole heating source during a fixed time period. For many regions a good time would be between 1600 hrs and 1900 hrs every evening, coinciding with the peak electrical demand. This would ensure drying out of the flue system, eliminate electrial use at a potential peak time and still use an optimum amount of electricity. The oil furnace would also take the full heating load at the colder outside temperatures.

CONCLUSIONS

There may be a problem of increased chimney deterioration with plenum heaters, if they are going to be run to displace more oil merely by having a lower outside temperature set-point. This problem is likely to be accentuated by increased tightening of homes which will increase internal humidity levels. Moist house air will flow up the chimney, condense and migrate into the motar, freezing and thawing and causing outside and inside deterioration of the chimney. In the worst case, the interior of the chimney might collapse and cause flue blockage. Since this may occur even in chimneys that are in good condition, defective chimneys, of which there are a large number, would be even more prone to this problem. Defective chimneys should be repaired or relined before a plenum heater is installed.

Although there is the remote possibility that ice blockage might occur at the top of the chimney, this is not considered to be a likely occurence, except in extreme conditions.

A more severe problem may exist with a different type of control strategy - a two-stage thermostat operation throughout the winter. This may result in continuing condensing conditions when the oil furnace is firing on a reduced cycle length in cold ambient temperatures. Under such conditions, rapid chimney deterioration is possible.

The most satisfactory system appears to be one allowing a certain amount of oil use every day, as the only heating source for a specified period. For many regions, a convenient period would be between 1600 hrs and 1900 hrs every evening, coinciding with their peak electrical demand. The oil furnace would also take the full heating load at the coldest outside temperatures. The flue system would be dried out daily, electrial use eliminated at a potential peak time and an optimum amount of electricity still used, while not running the risk of short cycles that the two-stage thermostat might present.

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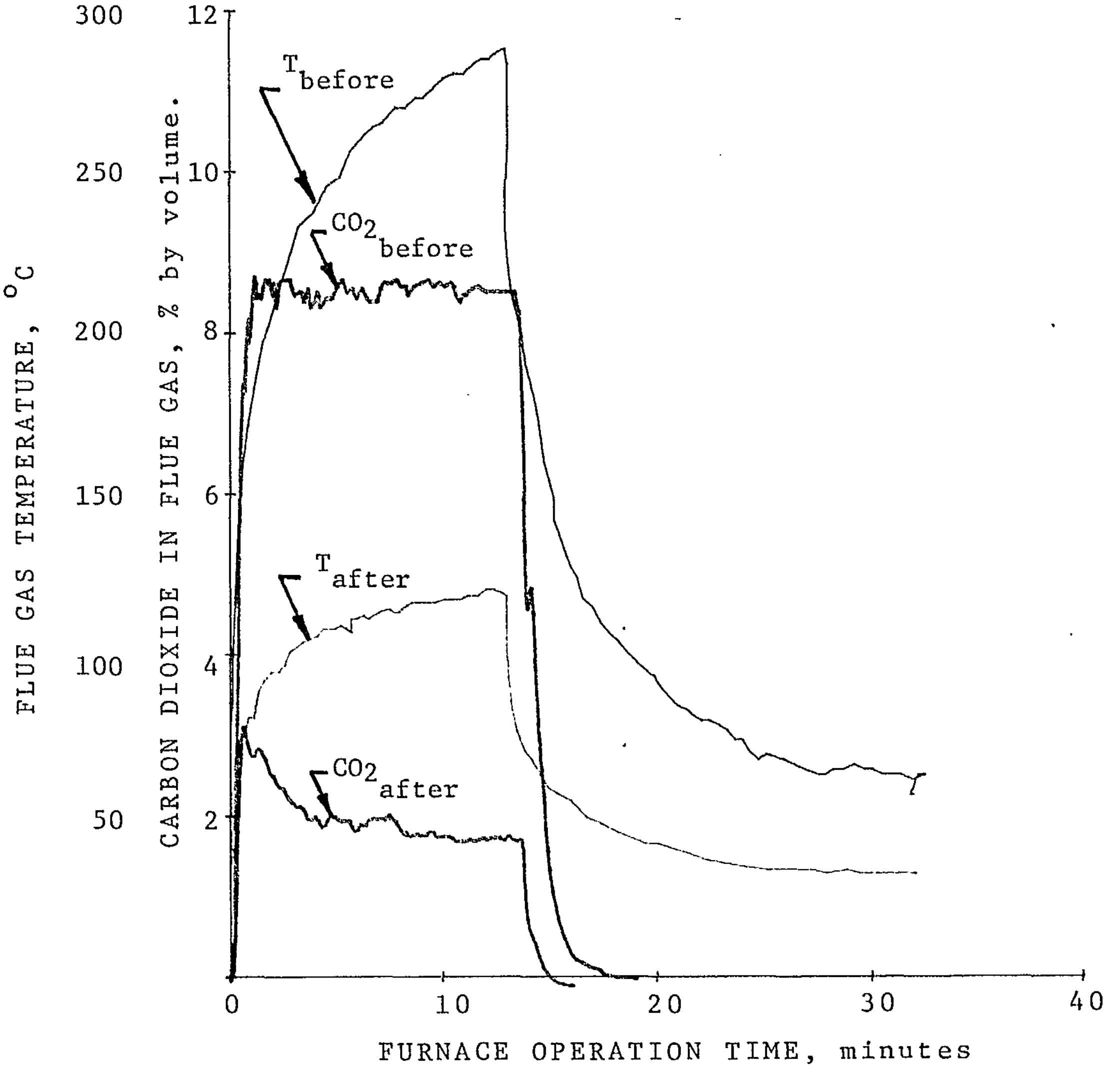

Figure 1. Effect of dilution on flue gas temperature and composition, House A.

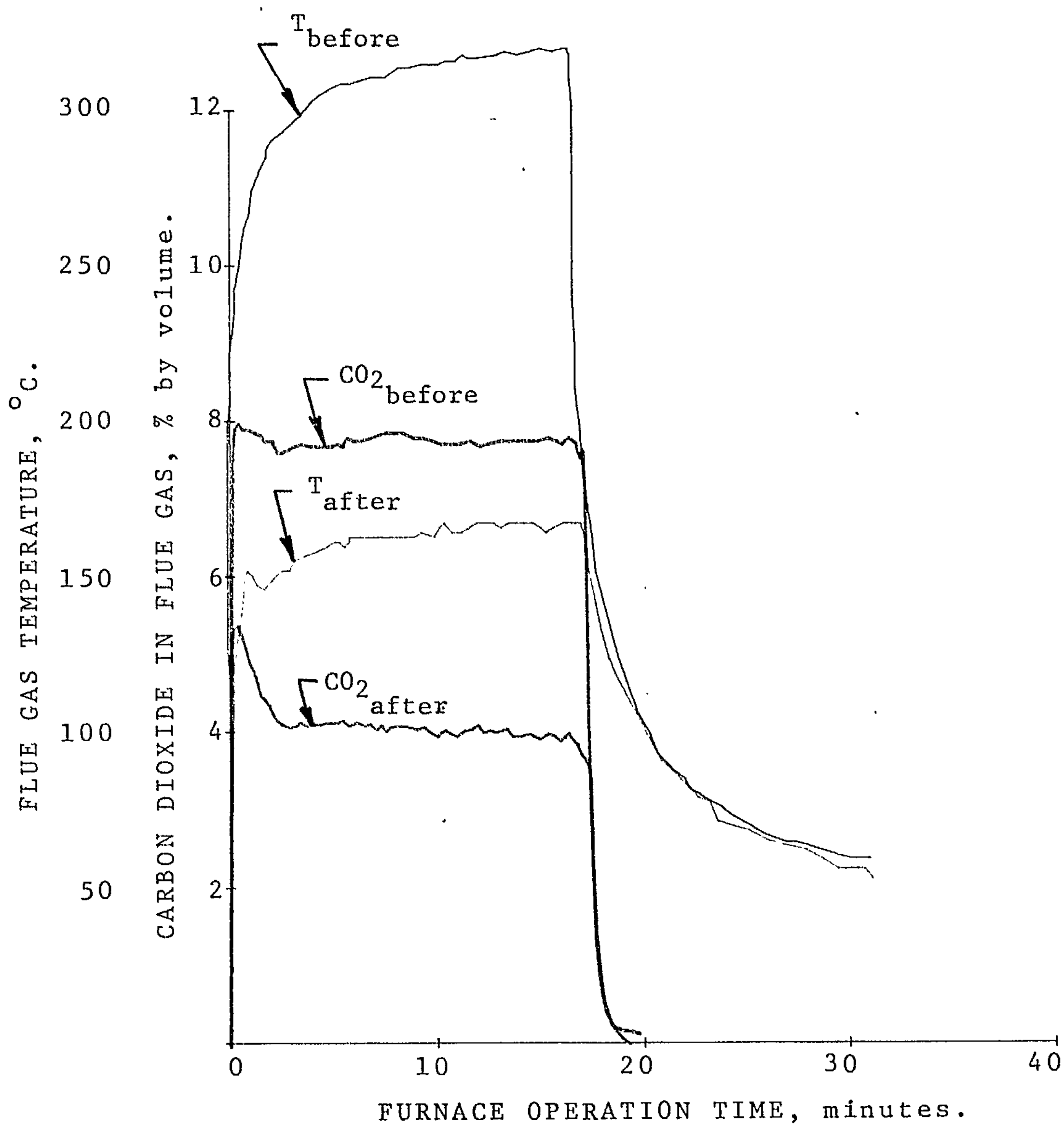

Figure 2. Effect of dilution on flue gas temperature and composition, House B.

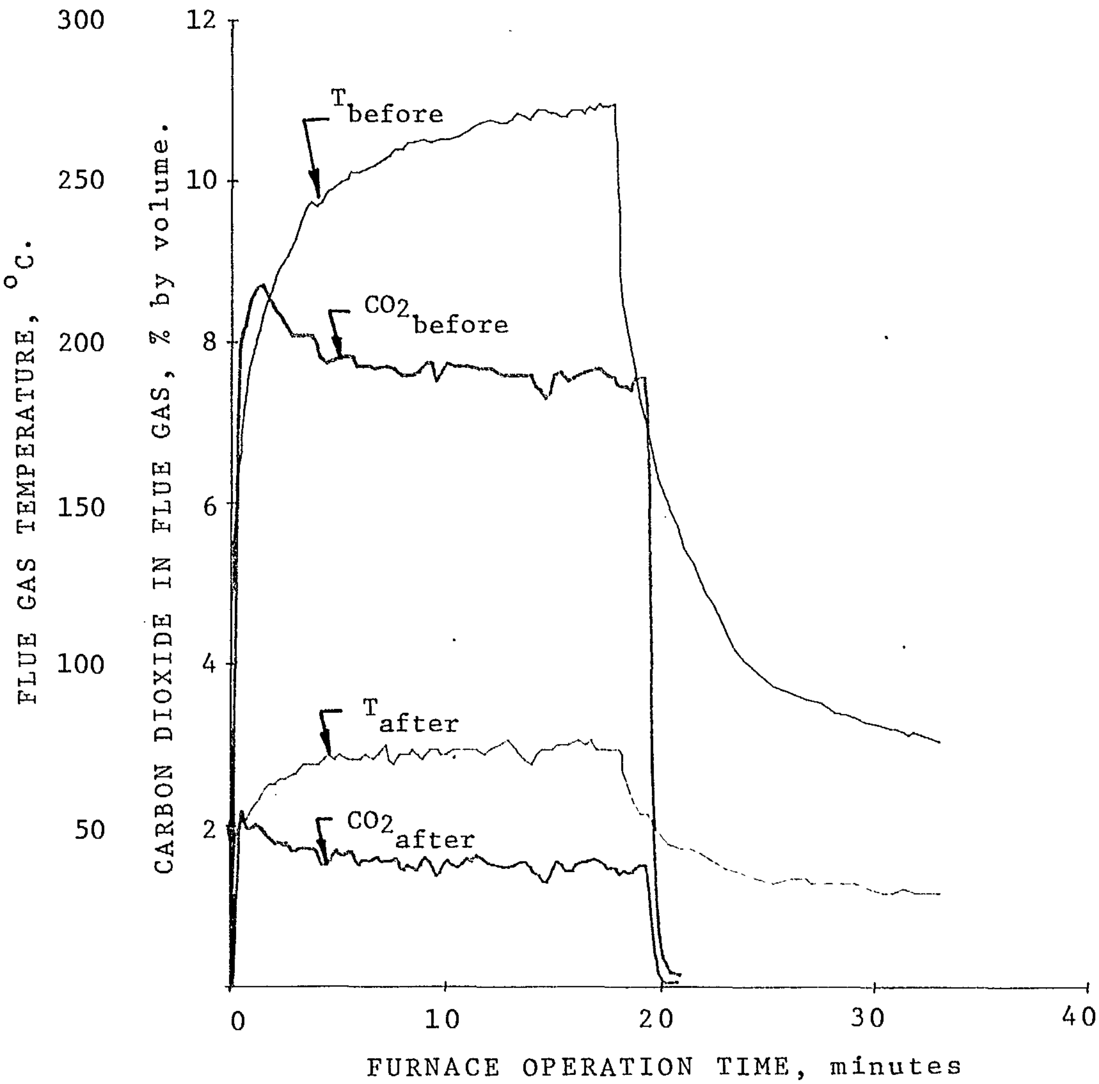

Figure 3. Effect of dilution on flue gas temperature and composition, House C.

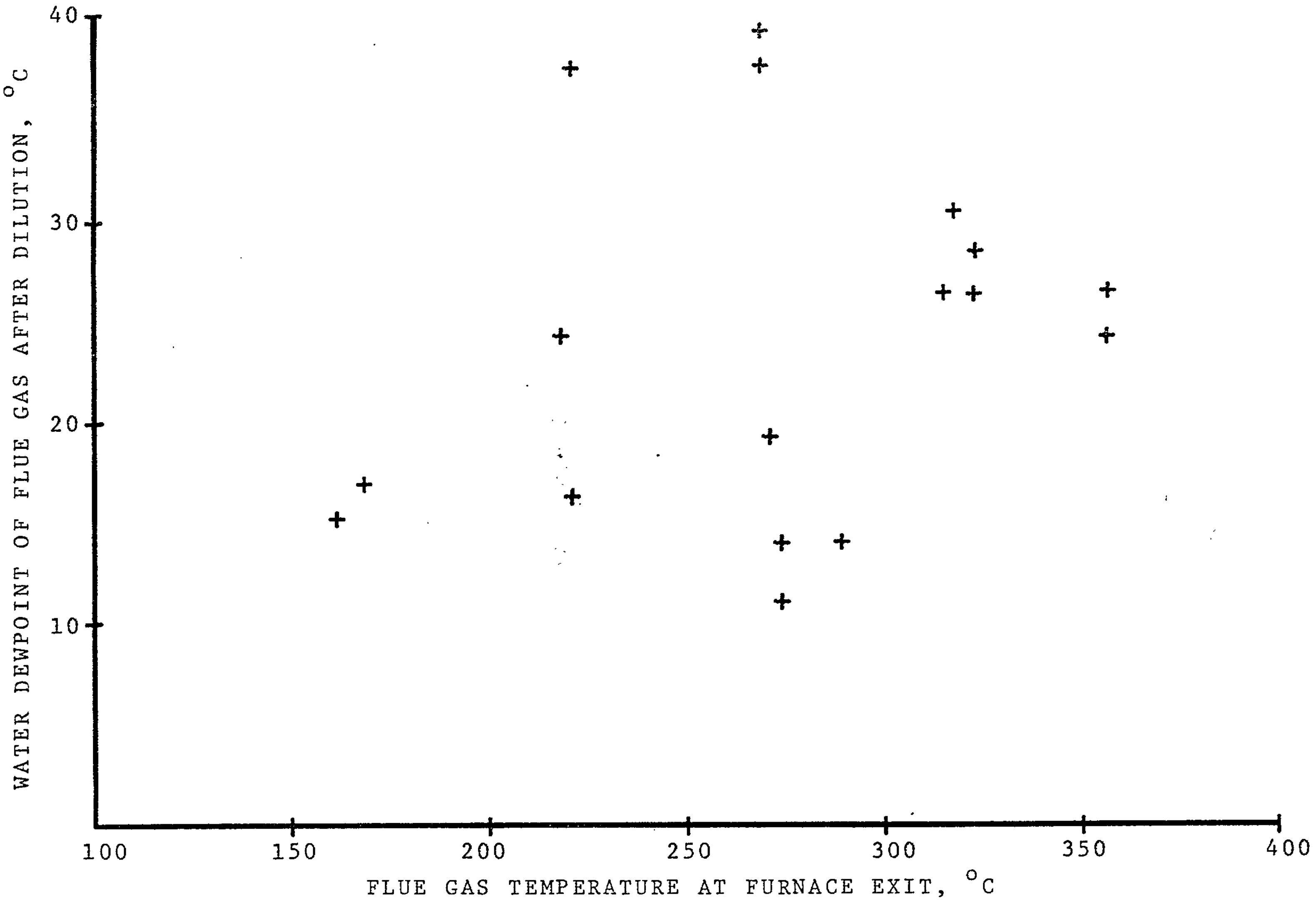

Figure 4. Variation in water dewpoint at chimney base with furnace exit temperature, for a number of oil-fired furnaces in the field.