The development of an oil-conversion burner
by Clark B McKee

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering
Montana State University

Abstract:
An oil-conversion burner for use In small domestic stoves Was developed under the auspices of the Montana State College Research Foundation. Requirements for this burner were that it be safe, that it give clean, efficient combustion, and that it operate with natural draft only and require no auxiliary devices, The burner which has been evolved apparently meets all the above requirements, and has a maximum smokeless capacity of 62,000 Btu. per hour input. It differs from other conversion burners in that a preheater is used to vaporize the oil before it is burned, the reason being that gaseous hydrocarbons burn with less soot than do liquid or mixed-phase hydrocarbons.

It is believed that this burner warrants further commercial investigation and development. Its inherent cheapness and success in meeting its requirements seem to indicate this.

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ABSTRACT

An oil-conversion burner for use in small domestic stoves was developed under the auspices of the Montana State College Research Foundation. Requirements for this burner were that it be safe, that it give clean, efficient combustion, and that it operate with natural draft only and require no auxiliary devices.

The burner which has been evolved apparently meets all the above requirements, and has a maximum smokeless capacity of 62,000 Btu. per hour input. It differs from other conversion burners in that a preheater is used to vaporize the oil before it is burned, the reason being that gaseous hydrocarbons burn with less soot than do liquid or mixed-phase hydrocarbons.

It is believed that this burner warrants further commercial investigation and development. Its inherent cheapness and success in meeting its requirements seem to indicate this.

I INTRODUCTION

There are at the present time a great number of oil conversion burners for domestic stoves on the market. According to one estimate, at least 50 nationally known concerns are engaged in the manufacture of such burners, and any number of small shops are doing likewise. However, comparatively few of these burners are really satisfactory. Compared with gas conversion units, they are inefficient in the use of fuel, and are harder to keep clean because of the greater soot-forming tendencies of oil. Several manufacturers, notably Montgomery Ward and the Breese Company, offer burners which have largely circumvented these objections, but in so doing they have raised still another objection, that of cost. The object of this project has been to develop a burner which will give clean, efficient operation and have a low initial cost. Specifically desired is a unit suitable for small, rural stoves.

Before examining this project in more detail, a brief survey of the oil conversion burners now on the market is in order. Although there are many modifications, they fall basically into one of two classes; either the pot type or the pressure atomizing type.

The mechanism of the pot type burner is as follows: oil flows from a tank through a constant-level feed regulator into a basin or pot. The heat of the flame burning above this basin causes the oil to vaporize. As the vapors rise from the pot, they pass by air-inlet holes, and the entering air causes combustion. This burner is made in far greater numbers and by more companies than any other variety. The Coleman Stove Company, for example, uses this type for nearly all the conversion units it makes. The pots are about 6" to 10" in diameter, depend upon gravity feed for the oil flow, and their rated input varies from 20,000-75,000 B.t.u. per hour for the water heaters, and up to 300,000 B.t.u. per hour for the bigger furnace units.

Three other manufacturers of the pot-type burner are the Queen Stove Company, the H. C. Little Company, and the Kresky Company. The products of the Queen Stove Company and the Kresky Company are quite similar to those of the Coleman, and are typical pot burners. H. C. Little's unit is different in that the oil passes from a cold to a hot region on an elongated pan, thereby being allowed to warm up and vaporize gradually instead of immediately, as the Coleman burner. As a result, less carbon laydown is claimed for this burner than for the ordinary pot burner. If this is true, it is because the more gradual heating would lead to less violent boiling under the combustion zone, fewer oil droplets in this zone, and consequently, a closer approach to vapor phase combustion than to mixed phase.

In a pressure-atomizing burner, oil and air are forced through a carburetor-like device where the oil is sprayed into the air as droplets. The mixture then goes through a nozzle at a velocity greater than the flame propagation velocity of the mixture, and is burned. The advantages of this type of burner are greater efficiency, greater flexibility regarding feed range and composition, and less sooting. However, the cost installed is high ($100 and up), and furthermore, electricity is required to operate the fans creating the forced draft. Breese, Montgomery Ward, and Monarch all manufacture burners of this type.

There are a number of variations of the basic types described above. One is the burner built by Therm Company, in which oil flows into a pan by gravity, much as in the pot-type. Air is blown in under pressure, passes over the pan of oil, and combustion takes place immediately. Another example is the Crane burner built by Crane Company, which shoots the oil out under pressure in a stream. Air enters the stove under natural draft, meets this oil, and combustion takes place.

During the war, Coleman produced an oil conversion burner in which oil dripped from a line in the top of the stove to a plate where it was vaporized and burned. In some respects this burner was very good, but it had the disadvantages of over-heating and over-sooting the stove. Also, it could not use the automatic level regulator as a protection against spilling the oil.

The burner which has been developed during the past year in the Montana State College chemical engineering laboratory is distinguished from the other types by its basic principle of pre-combustion vaporization. The oil flows through a constant-level regulator to a pre-heater located in front of the burner mouth, and in this the oil is vaporized. The resultant gas then passes from the preheater to the burner where it is mixed with air and burned. The reason for preheating the oil to a gas is that vaporized hydrocarbons tend to burn with less carbon laydown than liquid or mixed phase hydrocarbons burning under the same conditions.

II PROJECT HISTORY

This project was one of a number of research projects sponsored by the Montana State College Research Foundation, and it was the one given to the Chemical Engineering Department out of several suggested. It was undertaken because of the feeling that an inexpensive, yet efficient oil conversion burner is definitely needed, and that if developed, it would aid many of the people of Montana.

Work was begun on the project during Fall Quarter, 1948, and was continued through Summer Quarter of 1949. During this time, four different burners were built and put into operation in a Dixie No-Smoke coal burning space heater, and only the last of these is shown on drawings Nos. I through V. All of these burners have had several things in common. That is, each one employed a preheater to vaporize the oil; each was a horizontal gun-type unit introducing the air through a central section of pipe, and the oil into an annular space formed by this pipe and a larger diameter pipe on the inside of the stove; each one has used only the stack effect as a source of draft.

The first of these burners had a section of 1" standard pipe as an air inlet, and a piece of 2" pipe surrounding it inside the stove. Operation of this unit gave very large amounts of smoke for several reasons. The air inlet was too small, there was no baffling arrangement to mix the air and fuel, and the stovepipe was then too short to provide sufficient draft pressure. Nevertheless, a number of things were learned from this burner. For example, it was found that the stove must be sealed against the entrance of any air, excepting that going through the burner to the combustion zone. When this was done, there was somewhat less sooting and much less flashing of the oil vapor into the room (vapors were sometimes forced out the air inlet pipe into the room as a result of down drafts, and there these vapors flashed). It was discovered also that the major portion of the succeeding work was not to be the construction of a suitable preheater (as previously supposed), but rather the development of a burner to handle the vapors from the preheater.

The second burner at first consisted of a 2" inlet pipe surrounded by a short section of 3" pipe which contained the oil. This was a great improvement over the first unit, and even gave smokeless operation at low feed rates. Still, no baffling was used for mixing the air and oil. After having tried out this burner extensively, it was thought desirable to increase the amount of air in the secondary air zone, and another 2" inlet pipe was provided for this purpose. It delivered secondary air to a chamber built onto the end of the original burner. (Primary air is a limited amount of air introduced into the oil vapor prior to actual combustion. It is insufficient in amount to cause much combustion by itself. Secondary air is introduced later, and in the case of this burner, is the final quantity of air added. It is also here that the flame begins. This scheme of air introduction is a general one for most liquid and gas fired burners, since it increases combustion efficiency.) However, results with this modification were no better than with the original burner No.2, and this burner was also discarded. By now it was apparent that the principal problem was to get still more air, but at higher velocity and with sufficient turbulence so as to mix it well with the oil vapors. Consequently, in addition to constructing the third burner, several more lengths of insulated stovepipe were added to the height of the stack and surmounted by an A-frame cap. This cap is one of several common devices designed to be mounted on the end of a stovepipe chimney to protect it from downdrafts, rain, etc. This particular cap was manufactured from a standard design by the Bozeman Sheet Metal Works of Bozeman, Montana.

The third burner utilized a 4" section of pipe for the air inlet, and a dethreaded 5" coupling as the outer wall of the oil chamber. The interior end of the 4" pipe was covered by a steel plate and air entered the annular oil vapor chamber through slots cut in the side of this pipe. Another modification was the use of an orifice welded onto the flame end of the 5" coupling in an effort to induce turbulence and better mixing. This burner cut down on the amount of smoke, but indicated that for better performance, some sort of adjustmant of the inlet holes was needed. For that reason, a sleeve was designed which slid back and forth in the 4" inlet pipe covering or uncovering the various holes. Best results occurred when only about a square inch of hole was left uncovered in the primary air region, and about two square inches in the secondary air region.

On a final run of the third burner, an attempt at eliminating the need for the preheater was made. Oil was fed directly into the pan of the burner in hopes that the heat of the flame would vaporize it. This attempt did not work. The oil temperature stayed too low for complete vaporization.

From this burner several things were learned. One was that two factors, both vitally essential to successful combustion, definitely conflict between themselves. These factors are amount and velocity of incoming air. It was found that when the air openings were large enough to permit a great deal of air to enter, the air flowed in so slowly that it did not mix at all well with the oil vapors. Conversely, when the openings were too small, insufficient air got to the fuel, though it was under high velocity. Here the amount of air varied inversely as the velocity of air. The principal problem, then, became one of trying to reconcile these factors to an optimum. Another thing learned was that the vapor line from the preheater to the burner must not contain any dips. When a dip in the line occurred where the oil could accumulate before reaching the burner, surging and possibly back firing would occur during the initial minutes of the run while the oil was still liquid. The importance of sealing the stove against air leaks so as to maintain good draft pressure was also re-emphasized by this burner's performance.

With all these facts in mind, the fourth and final burner was built. As the drawings indicate, this burner was built so that the front wall of the 4" air inlet pipe and the forward orifice could be moved back and forth while the burner was operating. These adjustments were provided in order that optimum conditions might be determined more quickly. The number and size of the primary air holes was determined by adjusting the movable sleeve while running burner number three, and applying the data to burner number four.

The fourth burner was tested extensively, imperfections were removed from it, and a week-long run was made as a final test. During this run, the burner very seldom produced more than a faint trace of smoke, exhibited no back-firing tendencies even when high winds blew across the stack, and was not affected by its long exposure to combustion. With this test, experimental work on the burner was completed.

III DESIGN AND OPERATION

As previously noted under Project History, all but one of the burner systems have followed the same basic flow system: oil flows from a storage tank to a constant-level feed rate regulator, from which it proceeds to an enclosed preheater inside the stove. Here the oil is vaporized by the heat of the burner flame. Now in a gaseous state, the oil goes to the burner proper where it is mixed with air and burned. In the one exception to this system, the oil was fed directly from the rate regulator to the burner pan where it was hoped that heat radiation from the flame would vaporize the oil without having to use a preheater. However, it was discovered that insufficient heat was radiated back to vaporize the oil completely, and this flow system was abandoned in favor of the preheater.

The design factors affecting burner performance can be classified under stack, stove, burner, preheater, and flow system. Each of these sections will be discussed from the standpoint of the experimentation done with it.

A. STACK

Because this burner requires high velocity inlet air and high turbulence for successful combustion, the amount of draft obtainable is of great importance. Results indicate that a draft pressure of at least 0.04" of water is necessary for good operation. To obtain this pressure, a 17 foot stack of

6" stovepipe was used. To prevent downdrafts and keep moisture out, this stack was surmounted by an A-frame cap. Also, it was insulated in order to keep the flue gases hot and thereby maintain draft pressure. One source of draft loss was two sharp right angle bends in the pipe. This pipe should be straight or at least only gradually curved if turbulence and friction losses are to be avoided.

With the above-described stack, a constant draft pressure of about 0.05" H_2O is maintained. Fluctuations are slight, and occur only when a high wind blows over the top of the stack. No down-drafts have yet been encountered with this stack.

B. STOVE

The stove used was a Dixie No-Smoke coal burning space heater, No. 2R-30-8J, made by the Dixie Foundry Company, Inc., of Cleveland, Tennessee. One panel of firebrick was removed, and a hole was cut in the front wall to allow insertion of the burner. To maintain the draft, thereby avoiding sooting and backfiring, it was necessary to seal all air openings to the outside, excepting, of course, the burner's inlet. It is recommended that in any stove using this type burner, a mass of firebrick be installed for the flame to impinge upon; otherwise the stove body might be harmed.

C. BURNER

As mentioned previously, the major problem was to obtain sufficient air to mix thoroughly with the oil vapor. Drawings No. I through V, which are of burner No. 4, illustrate the solution to this problem. Drawing No. I is of the body of the burner, No. II illustrates the preheater, No. III, the outer orifice which aids in the mixing of the air and oil vapor, No. IV the deflection plate which guides the introduction of secondary air, and No. V is the assembly drawing of the whole burner, including the plate used to mount it on the stove. Briefly, air is admitted to the oil through relatively small entries, and only in certain places. The mixture is then drawn past orifices and chambers in order to induce more turbulence and fully burn the oil. It will be noted that the burner and other equipment pictured are shown exactly as built and used. These drawings are not intended for direct use in making more units because they include the design items which were needed to determine the operation variables, and these would not be needed in future units. Certain of these items are immediately apparent.

D. PREHEATER

The preheater is a 1" standard short nipple sealed off by caps at each end as shown in drawing No. II. Oil is introduced through 1/4" copper tubing into the bottom of the heater. Vapors leave through flexible tubing (about 1/2" I.D.), and proceed to the burner. A thermocouple was installed to check the oil temperature, which should vary from 300-400°C. A temperature of 300°C. is slightly over the ASTM distillation end point for No. 1 fuel oil, and 400°C. is somewhat below cracking temperature. In other words, the oil should be completely vaporized, but it should also be below the temperature where cracking and carbon formation may occur. Maintaining this range is difficult, because even on a single feed setting, the temperature has been known to vary more than 100°, depending on the draft and the composition of the feed. Best results, however, were observed when the preheater was placed as close to the burner mouth as possible. Another item on positioning the preheater is that its centerline must be below the lowest point of the outer orifice's rim. Otherwise, the constant level feed regulator must be placed so high that liquid oil flow to the burner will not stop before the oil level overflows the orifice rim.

E. FLOW SYSTEM

Oil was stored in a five-gallon container, from which it flowed by gravity through 1/4" copper tubing to a constant level feed regulator. This regulator, manufactured by the Detroit Lubricator Company, and typical of the regulators used on most oil stoves, serves the dual purpose of maintaining a constant feed rate, and of not allowing the oil level on the downstream side to rise beyond a certain point. This latter factor is a safety measure to prevent oil spillage from the burner pan. The regulator number is OTU 216, and its capacity is 34 cc's per minute.

From the regulator, the oil went by another length of 1/4" tubing to a fitting in the steel plate by which the burner was attached to the stove wall. This fitting carried the oil inside the stove and introduced it into the tubing which led to the preheater. This piece of tubing was well insulated against the burner flame, because burner operation prior to this insulating was twice halted, due to carbon in this tube, formed by cracking, which in turn was the result of overheating.

From the preheater, the oil vapor passed through a length of 1/2" flexible tubing to the burner. As previously mentioned, this line and its connection to the burner had to be arranged to permit no dips in which oil might accumulate. When this was not done, vapor pressure in the preheater would force large amounts of accumulated oil over into the burner all at once, then little oil would reach the burner until the next surge.

The oil vapors coming from the preheater entered the annular space showed on drawing No. I. Moving forward, they passed by a row of holes in the four inch pipe, details of which are shown on the same drawing. Primary air entered here, causing partial combustion. Then the gases moved forward, were brought close to the four inch pipe by the inner orifice, passed by the deflector (Figure No. 5) where secondary air was added, by the outer orifice, and finally into the stove where combustion was completed.

Of interest on drawing I are the angle of the deflection plate, the uneven curve of the inner orifice, and the small slot in the inner orifice. The first two factors were found necessary by experimentation, and probably result from uneven oil vapor distribution in the annular space. The slot was cut to allow liquid oil to flow out to the space behind the outer orifice, and burn. (This, of course, is before the system becomes hot enough to vaporize the oil.) If it were not present, liquid oil would rise through the primary air holes into the air inlet pipe, and this would lead to backfiring and spillage.

Details of the burner and its parts appear on drawings No. I through V. These drawings represent the final experimental burner and should not be considered as plans for a production model, though such plans could be derived from them. One item not shown is a cylindrical screen about 4" long and covered with a screen disk at its outer end. This was placed over the mouth of the burner and extending out into the room, and is intended to serve the dual purpose of keeping foreign material out of the burner, and preventing any flashbacks from entering the room. The diameter of the screen, of course, is about the same as the diameter of the air inlet pipe. While no flashbacks have ever occurred during operation of the ultimate test burner (number 4), the added precaution of this screen is deemed desirable.

IV RESULTS

The burner operates with no more than a very faint trace of smoke up to a feed rate of 27 mls. of No. 1 fuel oil per minute. Assuming a heating value of 145,000 B.t.u. per gallon of oil, this is equivalent to an input of 62,000 B.t.u. per hour. This compares with maximum rated capacities of 20,000 to 100,000 B.t.u. per hour for existing burners in the same general size range. Above the 27 ml. per minute feed rate, the amount of smoke gradually increased, but the burner was able to handle the additional load safely, even if not with highest efficiency. Minimum heat input allowable for operation was 14,000 B.t.u. per hour. It should be noted that the burner capacity is a function of the size of the burner, and of the stove. Greater heat input could be obtained with a larger burner, and conversely, a smaller burner could be constructed for lesser requirements.

Up to the indicated feed rating, the flame varied in color from yellow to bright orange, depending on the rate of feed, and upon the amount of draft. Flame length seldom exceeded 1-1/2 feet, and usually was much shorter. These conditions indicate efficient combustion.

Noise caused by the burner was a steady, low pitched "combustion rumble".

Operation is begun by turning on the regulator and filling the pan on the burner with liquid oil. A few squares of toilet