DESIGN CONSIDERATIONS FOR A DIRECT-FIRED PROPANE HEATER TO PREHEAT THE BASE FOR COLD-WEATHER PAVING

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A prototype direct-fired propane heater with variable gas rate and speed was designed for preheating the base to study cold-weather paving of thin mats. The results obtained were compared with those predicted by the computer program. The computer program was then used to simulate cold-weather paving. Statistical analysis of the data revealed that only three of the eight variables were significant. The effect of these three significant variables on the time available for compaction was found to be linear. A nomogram was constructed to predict the time available for compaction. From the results of this study, a 12 by 12-ft (3.6 by 3.6-m) propane heater producing approximately 300,000 Btu/hr-ft^2 (9300 kW/m^2) and moving 2 min ahead of the paver at a speed of 20 to 80 ft/min (6.1 to 24 m/min) is recommended as a final design. Propane gas consumption for such a heater is estimated to be 1,980 lb/hr (890 kg/h), which will result in a fuel cost of \$138/hr.

•COLD-WEATHER paving of a thin mat is hampered by rapid cooling. Preheating the base is one method to retard this rapid cooling, and theoretical and practical aspects of base preheating have been studied (1, 2).

This study was undertaken to design a variable-speed propane heater to preheat the base before the thin mat is placed. The results of laboratory experiments were compared with those predicted by the computer program developed by Corlew and Dickson (2). The principal objective of the study was to determine the effect of some of the variables on the time available for compaction. The ultimate goal was to design a propane heater that could be used in real practice.

Laboratory experiments have been conducted in which test specimens of asphalt base were preheated with a direct-fired propane heater. These experiments were restricted to preheating and subsequent cooling of the base. Placing of thin mat on a preheated base was not considered. The capacity of the experimental heater was 90,000 Btu/hr-ft^2 (279 kW/m^2). The heater was stationary, which is impractical because the openings for the burner and air intake could not be changed, which made it impossible to adjust the flame. In the present study, most of these problems were overcome, and the laboratory experiments investigated base preheating and the placing of thin mat on the preheated base.

EXPERIMENTATION

The experimental setup is shown in Figure 1. The direct-fired propane heater was fueled from a 100-lb (45-kg) liquefied petroleum gas (LPG) tank. The gas flow rates were controlled by needle valves installed in the gas line just before the flow meter.

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Figure 1. Experimental setup for base preheating.

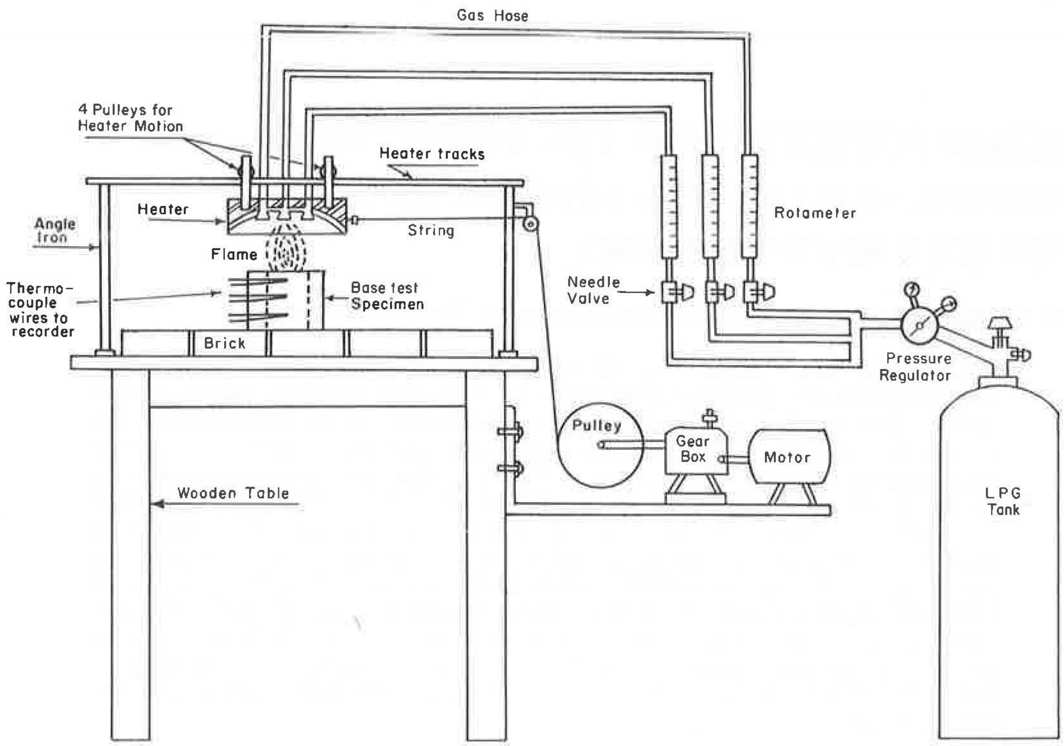
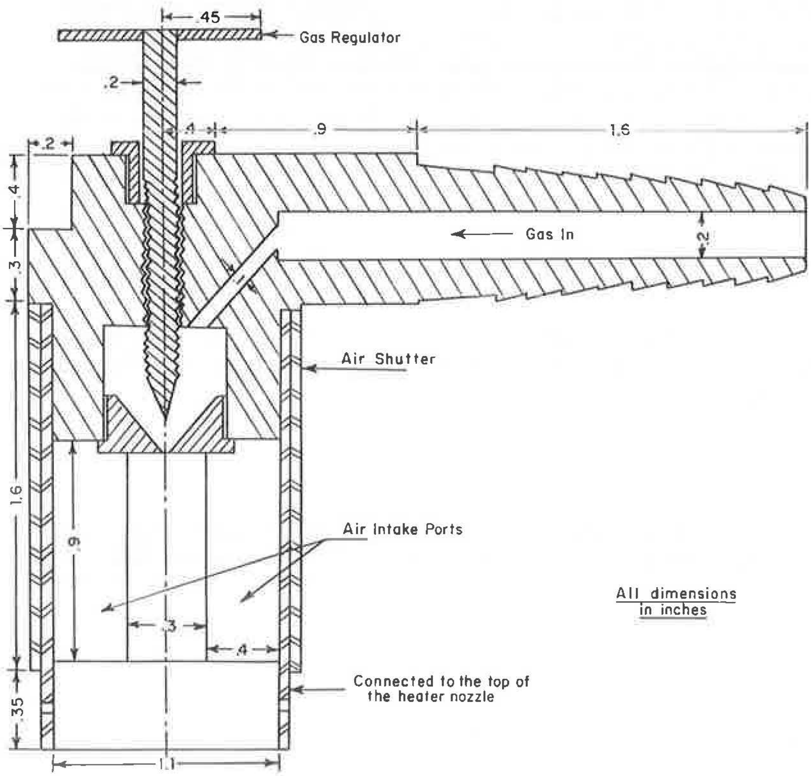


Figure 2. Burner design.



The gas was supplied from the flow meter to the variable-opening orifice of the burner. The burner design (Figure 2) was similar to the conventional Bunsen burner. The entire heater with four pulleys was mounted on two tracks, which were supported at both ends by angle irons. The heater was connected with a thick cotton string to a 6-in.-diameter (152-mm) pulley, which was driven by a ¼-hp (186-W), 1,725-rpm motor through a gear box. The lowest speed that could be obtained by using the gear box was 4 ft/min (0.02 m/s).

A detailed design of the heater is shown in Figure 3. The heater shell was made from $\frac{1}{16}$-in.-thick (1.6-mm) stainless steel 303 sheets. The top inner half of the heater was filled with asbestos paste to avoid heat loss. The heater was lined with ¼-in.-thick (6.4-mm) refractory, which was held in place by 14 anchors. The entire heater weighed approximately 10 lb (4.5 kg). The distance between the heater and the base specimen could be adjusted by raising or lowering the base specimen.

The experimental procedure mainly consisted of the following four steps:

1. Preheating the cold base specimen by moving the propane heater above it at a desired speed,
2. Cooling the base specimen during the stall period,
3. Placing the thin hot-mixed asphalt specimen on the base, and
4. Cooling the thin mat specimen from 300 to 150 F (149 to 66 C) on the preheated base.

During this period all the temperatures were recorded as a function of time on a 24-channel Acco Bristol recorder.

COMPARISON OF EXPERIMENTAL AND COMPUTED RESULTS

Nine experimental runs were made by using different combinations of heat output, mat thickness, preheat time, and initial base and mat temperature values. Comparison of experimental temperatures with computed temperatures for a few typical runs is shown in Figures 4, 5, and 6. Comparisons of only upper base points and all the points in the mat are given. The temperature changes below a certain depth in the base are insignificant during the preheating and stall periods. That is why the comparison at the point 1 in. (25 mm) from the top in the base is not given during preheating and the stall period. Also the comparison for the interfacial temperature is not given during these periods because of the experimental difficulties encountered in accurately measuring it.

In Figure 4, computed results are shown for 10, 20, and 40 percent heat losses. The computed temperature profile does not significantly change; hence, the effect of heat loss is probably insignificant. The same conclusion will be reached later on the basis of systematic statistical study of the variables.

Figures 4 and 5 show that there is a considerable difference between the experimental and computed results. However, in all cases mat cooling was slower for the experimental results than for computed results. This apparent disparity between the experimental and computed results could be due to existence of a thin layer of air between the two samples. The layer of air between the samples acts as an insulation, which retards the cooling of thin mat. For the run shown in Figure 6, the thin mat specimen was hammered periodically after it was placed on the preheated base specimen. The close contact between the hammered samples resulted in greater agreement between experimental and computed results.

To quantitatively explain the effect of a thin layer of air between two samples, the computer program was modified to take into account this resistance. Computer runs were made with 0, $\frac{1}{80}$, $\frac{1}{40}$, and $\frac{1}{20}$-in.-thick (0.3, 0.6, and 1.2-mm) layers of air between samples, and it was found that $\frac{1}{40}$ in. (0.6 mm) of air gave good agreement between the experimental and computed results. The results in Figure 5 show that the agreement between the experimental and modified computed result is considerably improved.

Figure 3. Detailed design of heater.

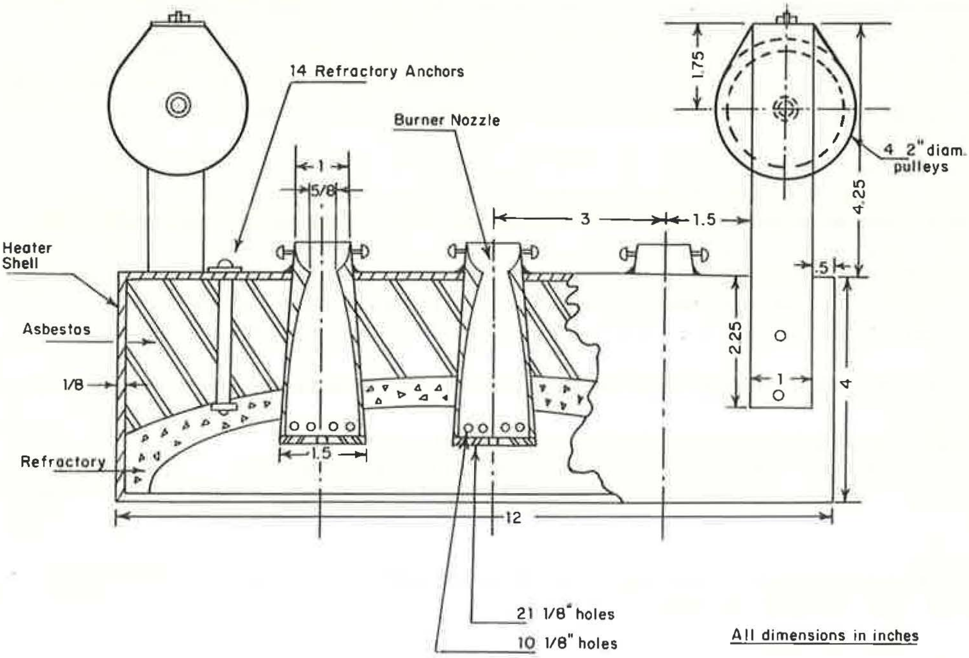
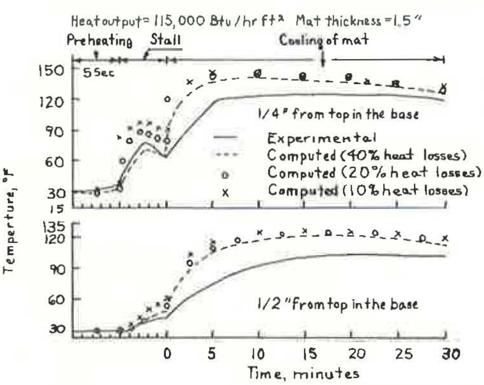


Figure 4. Comparison of experimental results and computed results for 10, 20, and 40 percent heat losses.



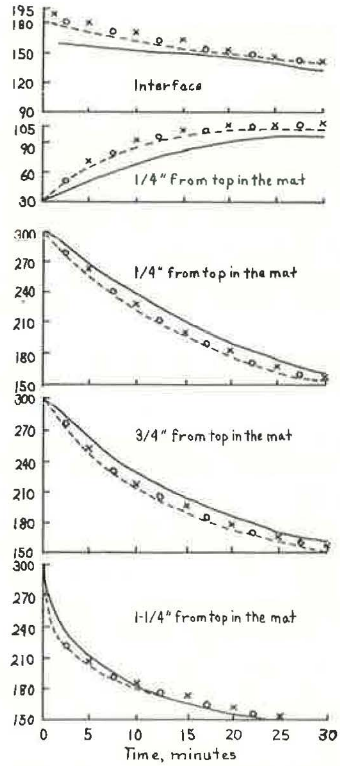
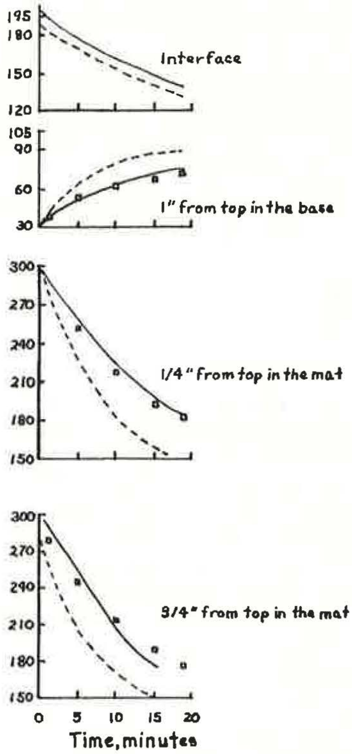


Figure 5. Comparison of experimental results and computed results, including $^1/_{40}$-in. (0.6-mm) air layer.



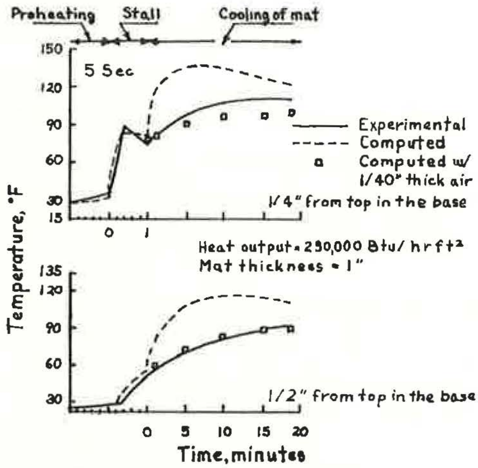
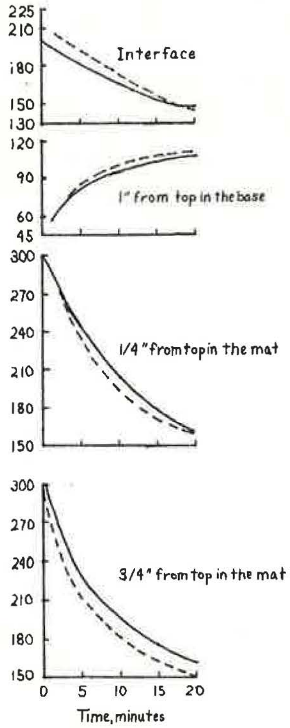
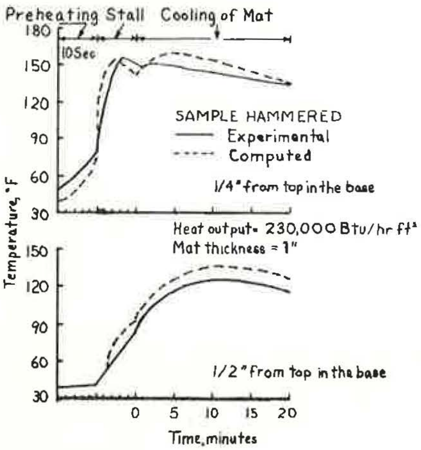


Figure 6. Comparison of experimental and computed results for hammered samples.





SIMULATED COLD-WEATHER PAVING

The computer program developed by Corlew and Dickson (2) was used to simulate cold-weather paving. For the purpose of preliminary study, eight variables were investigated at two levels each (Table 1). The dependent variable was time to cool to 175 or 150 F (79.4 and 66 C). Initially 16 computer runs were selected. The detailed statistical analysis for these 16 runs, together with confounding of some interactions, is given by Shah (3). The following factors were found to be significant at the 5 percent level (in decreasing order of importance):

1. Mat thickness,
2. Wind velocity, and
3. Preheat time.

The results were the same for time to cool to both 175 and 150 F. None of the second-order interactions was found to be significant.

Mat thickness and wind velocity were found to be the most significant variables. The same conclusion was reached by Shah and Dickson (4) in their study on use of insulation in cold-weather paving. Surprisingly heat output was not found to be significant; however, a close examination would reveal that heat output is connected with preheat time, and in this case preheat time is significant.

Stall period is not significant, which means that we can be flexible in setting the distance between the heater and paver. Initial base temperature or atmospheric temperature is not significant, which means that minor changes or fluctuations in the environmental temperature would not appreciably change the design conditions. We can be flexible in designing the heater capacity because heat losses and heat ouput are not significant. Small changes in lay-down temperature do not significantly affect the time available for compaction. Preheat time is found to be significant, and, depending on the preheat time required, the heater speed should be adjusted. To synchronize the various operations requires that the heater and paver move at nearly the same speed. It should be remembered that these conclusions are strictly valid within the range of the variables studied.

Based on the results of this analysis, 48 more computer runs were made. For these runs preheat times of 9, 18, 27, and 36 sec; mat thicknesses of ½, 1, and 1½ in. (12.5, 25, and 38 mm); and wind velocities of 0, 5, 10, and 15 mph (8, 16, and 24 km/h) were used. These data were utilized to find a relationship among time to cool to 175 or 150 F (79.4 or 66 C) and three significant variables by using a step-wise multiple linear regression program. The relationships were

$$\text{Time (150)} = 18.01\ (A) - 0.80\ (B) + 0.39\ (C) - 2.33 \qquad (1)$$

$$\text{Time (175)} = 12.88\ (A) - 0.54\ (B) + 0.30\ (C) - 2.64 \qquad (2)$$

where time is in min and

A = mat thickness in in. (mm),
B = wind velocity in mph (km/h), and
C = preheat time in sec.

A nomogram (Figure 7) was constructed to obtain the time available for compaction by a graphical procedure. Point G on the scale of mat thickness is joined by a straight line to point H on preheat time scale. Point I, which is the intersection of line GH with scale A, is joined by another straight line to point K on the wind velocity scale. Point J, which is the intersection of line IK with the time scale, gives the time available for compaction.

Table 1. Variables used in computer simulation.

Factor	Symbol	High Value	Low Value
Mat thickness, in.	X_1	1.5	0.5
Wind velocity, mph	X_2	15	0
Preheat time, sec	X_3	36	9
Stall time, min	X_4	3	1
Initial mat temperature, F	X_5	300	250
Initial base temperature, F	X_6	40	10
Heat loss, percent	X_7	40	20
Heat output, Btu/hr-ft^2	X_8	443,000	148,000

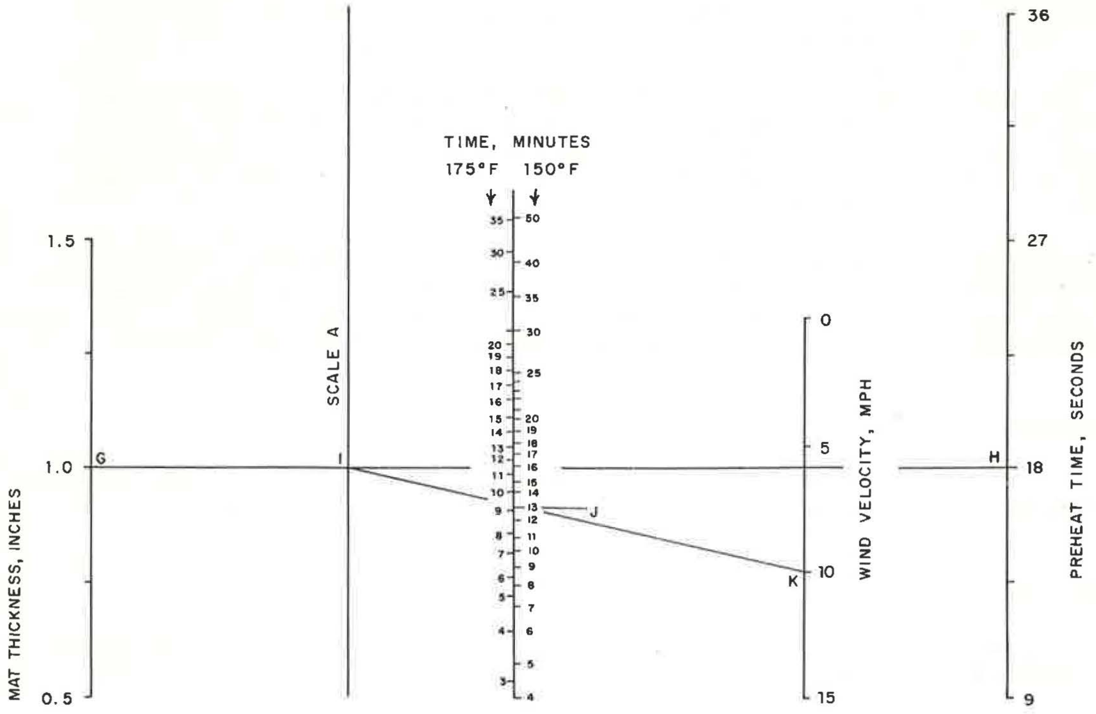
Note: 1 in. = 25 mm; 1 mph = 1.6 km/h; 1 F = 1.8 C + 32; 1 Btu/hr-ft^2 = 3.1 W/m^2.

Table 2. Base preheating versus insulation in cold-weather paving.

Mat Thickness (in.)	Preheat Time (sec)	Insulation Thickness (in.)	Time to 175 F (min)	Time to 150 F (min)
0.5	0	0	1.5	2.8
	9	–	2.7	4.7
	18	–	4.5	6.8
	27	–	6.1	9.0
	36	–	8.1	11.3
	–	1/16	5.0	6.8
	–	1/8	6.0	7.8
	–	1/4	7.0	8.7
1.0	0	0	5.5	8.3
	9	–	7.3	10.7
	18	–	9.7	13.7
	27	–	12	16.6
	36	–	14.3	19.2
	–	1/16	11	14.8
	–	1/8	12.8	15.9
	–	1/4	14.3	18.9

Note: 1 in. = 25 mm; 1 F = 1.8 C + 32.

Figure 7. Nomogram for base preheating.



Based on the results of this study and other data (4), a comparison of base preheating and insulation is given in Table 2. All data were obtained for 25 F (-3.8 C) base temperature and 10-mph (16-km/h) wind velocity. Based on heat transfer considerations, both methods seem to be equally attractive and efficient. However, from practical consideration, base preheating seems to be the more useful method.

From the results of this study, recommendations regarding the final design of the heater could be made. The breadth of the heater should be the same as the breadth of the paver. The length of the heater depends on preheat time required and the speed at which it is moving. Assuming paver speeds of 20 to 80 ft/min (6.1 to 24 m/min) in normal operations (5), a 12-ft-long (3.6-m) heater will give 36 to 9 sec of preheat time depending on the speed. Thus a 12 by 12-ft propane heater producing approximately 300,000 Btu/hr-ft^2 (9300 kW/m^2) and moving 2 min ahead of pavers at a speed between 20 and 80 ft/min could be recommended. Depending on the speed, the distance between the heater and paver would be between 40 and 160 ft (12 and 48 m). It is further recommended that the heater be designed so that the vertical distance between the burner and base surface can be changed as desired. The LPG consumption for such a heater is estimated to be 1,980 lb/hr (890 kg/h). The estimated fuel cost for LPG would be $138/hr based on the cost of LPG at $7/100 lb ($7/45 kg).

CONCLUSIONS

The results of this study suggest that a direct-fired, refractory-lined propane heater can be effectively used for base preheating to achieve adequate time for compaction of thin mats. Base preheating is the most useful method from practical considerations, even in the face of today's energy shortage.

The experimental results establish the validity of the mathematical model for predicting base preheating and cooling of mat. Statistical analysis showed that mat thickness, wind velocity, and preheat time are significant variables affecting the time available for compaction. The relationship among time available for compaction and these three variables is linear within the range of the variables studied.

A 12 by 12-ft (3.6 by 3.6-m) propane heater with approximately 300,000-Btu/hr-ft^2 (9300-kW/m^2) capacity is needed to achieve adequate time for compaction of thin mats. The heater should move 40 to 160 ft (12 to 48 m) ahead of pavers at a speed between 20 and 80 ft/min (6.1 and 24 m/min) depending on the preheat time required. The propane gas consumption would be 1,980 lb/hr (890 kg/h) at a fuel cost of $138/hr.

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