STUDIES FOR A NEW HOT AIR ENGINE

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PART II :

A Further Thermodynamic Analysis

Summary

The second part of the Thermodynamic Analysis for a New Hot Air Engine is devoted to an investigation into the effects and advisability of subdividing compression and expansion into stages, with cooling or heating applied respectively between two stages. The requirements of combustion air are considered and the behaviour of the plant at part-load for several governing methods are discussed. In the conclusions the broad principles for a design as emanating from the analytical treatment are worked out, and suggestions are made for a suitable design of simple manufacture and operation. After an assessment of the advantages and limitations of the hot air engine suggestions are put forward for further investigating fundamental data on which a future design can be based which would ensure reasonably favourable operation.

CONTENTS

1. Introduction

In Part I of this paper, the hot air engine cycle was described and some of its simple thermodynamic cycle characteristics were examined. In this part further and more complex characteristics will be studied, namely, the effect of using multistage units for compression and expansion, the distribution of air in the cycle and part-load operations, and from these conclusions will be drawn for a suitable construction of a hot air engine power plant as can be derived from theoretical considerations.

2. THE MULTISTAGE CYCLE

A glance at Tables II and III in Part I of this Report shows that the order of efficiencies and specific outputs to be expected from the hot air engine is very low. One of the possible methods of improving both efficiency and specific output is the introduction of multistage processes either for compression or for expansion or both.

As a first step, the effect is studied of converting the compression process into a two-stage process and retaining the expansion process as a single-stage process. Under assumed conditions of perfect intercooling and ideal intercooler pressure, the compression work is given by

$$L_c = \frac{2n}{n-1} RT_1 \left(1 - E^{\frac{n-1}{2}}\right) \qquad (58)$$

Introducing this expression into the expression for the efficiency

$$\eta = \frac{\eta_M \left(\eta_e L_e - \frac{L_c}{\eta_c}\right) - J\Delta h}{\frac{1}{\eta_B \eta_R} \cdot C_p J (T_3 - T_2')} \qquad (12)$$

and simplifying, one obtains

$$\eta = \eta_L \eta_M \eta_B \eta_R \frac{nR}{n-1} \frac{\left[\eta_e T_3 \left(1 - \frac{1}{E^{n-1}}\right) - \frac{2 T_1}{\eta_c} \left(E^{\frac{n-1}{2}} - 1\right)\right]}{C_p J (T_3 - T_2')} . \qquad (59)$$

In terms of the numerical values given in para 2 of Part I, this becomes

$$\eta = 0 \cdot 1516 \frac{\left[T_3 \left(\frac{E^{0.3} - 1}{E^{0.3}}\right) - 830 \cdot 7 (E^{0.15} - 1)\right]}{\bar{C}_p (T_3 - 300 E^{0.15})} . \qquad (60)$$

Similarly, the specific output is given by

$$L_s = \frac{\eta_L \eta_M}{76 \cdot 04} \frac{nR}{n-1} \left[T_3 \left(\frac{E^{n-1} - 1}{E^{n-1}}\right) - \frac{2 T_1}{\eta_e \eta_c} \left(E^{\frac{n-1}{2}} - 1\right)\right] \cdot \qquad (61)$$

In terms of the numerical values, this becomes

$$L_s = 1 \cdot 084 \left[T_3 \left(\frac{E^{0.3} - 1}{E^{0.3}}\right) - 830 \cdot 7 (E^{0.15} - 1)\right] \cdot \qquad (62)$$

From equations (59) or (61), the expression for $T_{3\ min}$ can be derived

$$T_{3\ min} = 830 \cdot 7 \frac{E^{0.3} (E^{0.15} - 1)}{(E^{0.3} - 1)} . \qquad (63)$$

Tables XI and XII give the numerical values of η and L_s respectively, for two-stage compression. The efficiency actually falls below that of the pure single-stage process in the region: $E < 8$ and $T_3 > 750°$ C. Beyond these values, an increase in η can be noticed, of a magnitude equivalent to raising T_3 by about 100° C. The specific output is $1\frac{1}{4}$ to $1\frac{1}{2}$ times higher at all temperatures and compression ratios. $T_{3\,min}$ is reduced by about 10% by the multiplying factor

$$2\,\frac{E^{\frac{n-1}{2}}-1}{E^{n-1}-1}\,. \tag{64}$$

If the two-stage compression with perfect intercooling is combined with the two-stage expansion, then

$$L_e = \frac{n}{n-1}\,RT_3\left(1+\frac{T_3'}{T_3}\right)\left[1-\left(\frac{p_4}{p_3}\right)^{\frac{n-1}{2n}}\right], \tag{65}$$

where T_3'/T_3 is the reheat factor, defined by the equation

$$T_3 < T_3'\;E^{\frac{n-1}{2}}\,. \tag{66}$$

Combining equations (12), (58) and (65), the overall thermal efficiency is obtained as

$$\eta = \eta_L\,\eta_M\,\eta_B\,\eta_K\,\frac{nR}{n-1}\,\frac{\left\{\eta_e\,T_3\left(1+\frac{T_3'}{T_3}\right)\left[1-\left(\frac{p_4}{p_3}\right)^{\frac{n-1}{2n}}\right]-\frac{2T_1}{\eta_c}\left[\left[\frac{p_2}{p_1}\right]^{\frac{n-1}{2n}}-1\right]\right\}}{C_p\,J\left(T_3-T_1\,E^{\frac{n-1}{2}}\right)} \tag{67}$$

or

$$\eta = \frac{15\cdot16\,(E^{0.15}-1)}{C_p(T_3-300\,E^{0.15})}\left[\frac{T_3}{E^{0.15}}\left(1+\frac{T_3'}{T_3}\right)-600\right]. \tag{68}$$

In a similar manner, the expression for the specific output is obtained, namely

$$L_s = \frac{\eta_L\,\eta_M}{76\cdot04}\left[\eta_e\,\frac{n}{n-1}\,RT_3\left(1+\frac{T_3'}{T_3}\right)\left(1-\frac{1}{E^{\frac{n-1}{2}}}\right)+\right.$$

$$\left.+\frac{1}{\eta_c}\,\frac{2n}{n-1}\,RT_1\left(1-E^{\frac{n-1}{2}}\right)\right] \tag{69}$$

or

$$L_s = 1\cdot084\,(E^{0.15}-1)\left[\frac{T_3}{E^{0.15}}\left(1+\frac{T_3'}{T_3}\right)-830\cdot7\right]. \tag{70}$$

By equating equations (68) or (70) to zero, $T_{3\,min}$ is obtained:

$$T_{3\,min} = \frac{830\cdot7\,E^{0.15}}{1+\frac{T_3'}{T_3}}\,. \tag{71}$$

Tables XIII and XIV give the numerical values of η and L_s respectively. An apparent increase in thermal efficiency of between 5 to 25% occurs over that of the single-stage process, the advantage increasing with increasing compression ratios. Nevertheless, this is more than offset, particularly for compression ratios of less than about 7, if the energy spent in reheating is taken into consideration, the decrease due to this being of the order of 5 to 12%. The importance of reheat is seen from the fact that the thermal efficiency falls below that of the single-stage process if the reheat is less than 75% of perfect reheat. The specific output is not appreciably increased over the previous case and remains at between 1¼ and 1½ times that of the single-stage process. $T_{3\,min}$ is decreased by about 20%.

If three-stage compression and expansion were to be used, then the respective compression and expansion work is given by the expressions

$$L_c = \frac{3n}{n-1} RT_1 \left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{3n}} - 1\right] \tag{72}$$

and

$$L_e = \frac{n}{n-1} RT_1 \left(1 + \frac{T_3'}{T_3} + \frac{T_3''}{T_3}\right) \left[1 - \left(\frac{p_4}{p_3}\right)^{\frac{n-1}{3n}}\right]. \tag{73}$$

Combining these with equation (12) gives

$$\eta = \eta_L \eta_M \eta_B \eta_R \frac{nR}{n-1} \frac{\left\{\eta_e T_3 \left(1 + \frac{T_3'}{T_3} + \frac{T_3''}{T_3}\right)\left[1 - \left(\frac{p_4}{p_3}\right)^{\frac{n-1}{3n}}\right] - \frac{3T_1}{\eta_c}\left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{3n}} - 1\right]\right\}}{\bar{C}_p J \left(T_3 - T_1 E^{\frac{n-1}{n}}\right)} \tag{74}$$

or

$$\eta = \frac{15 \cdot 16\,(E^{0.1} - 1)}{C_p(T_3 - 300\,E^{0.1})} \left[\frac{T_3}{E^{0.1}} \left(1 + \frac{T_3'}{T_3} + \frac{T_3''}{T_3}\right) - 900\right], \tag{75}$$

where

$$T_3 < T_3' E^{\frac{n-1}{3}} \tag{76}$$

and

$$T_3' < T_3'' E^{\frac{n-1}{3}}. \tag{77}$$

Similarly, the specific output is given by

$$L_s = \frac{\eta_L \eta_M}{76 \cdot 04} \frac{nR}{n-1} \left(E^{\frac{n-1}{3}} - 1\right) \left[\frac{\eta_e T_3}{E^{\frac{n-1}{3}}} \left(1 + \frac{T_3'}{T_3} + \frac{T_3''}{T_3}\right) - \frac{3T_1}{\eta_c}\right] \tag{78}$$

or

$$L_s = 1 \cdot 084\,(E^{0.1} - 1) \left[\frac{T_3}{E^{0.1}} \left(1 + \frac{T_3'}{T_3} + \frac{T_3''}{T_3}\right) - 1246\right]. \tag{79}$$

From equations (74) or (78), $T_{3\,min}$ is obtained as

$$T_{3\,min} = \frac{3\,T_1}{\eta_c} \cdot \frac{E^{\frac{n-1}{s}}}{1 + \frac{T_3'}{T_3} + \frac{T_3''}{T_3}}. \tag{80}$$

The numerical values of η and L_s are given in Tables XV and XVI respectively.

In all the multistage systems considered here, the gain in thermal efficiency is practically negligible, if the inevitably imperfect intercooling and reheat are taken into consideration, except for very high compression ratios working at low temperatures. Though the specific output is increased by about 25%, in view of the greater weight of the power plant, multistage units do not seem to be promising propositions for the small output reciprocating hot air engine.

3. Air Consumption

Under particular conditions of compression ratio, temperature and component efficiencies, the heat input into the power plant [from equation (12)] will be

$$Q_1 = \frac{C_p}{\eta_B\,\eta_K}\,(T_3 - T_2) \text{ kcal/kg process air.} \tag{81}$$

If B kcal/kg were the calorific value of the fuel used, the amount of fuel necessary will be given by the expression

$$F = \frac{\bar{C}_p\,(T_3 - T_2)}{B\,\eta_B\,\eta_K} \text{ kg fuel/kg process air.} \tag{82}$$

For any fuel, solid, liquid or gaseous, whose calorific value is in the region $3400 < B < 11{,}350$ kcal/kg, the amount of air necessary for the release of 10^6 kcal is 135·5 kg. Hence the amount of air necessary to burn the fuel in equation (82) is given by

$$A = \frac{a\,\bar{C}_p\,(T_3 - T_2)}{738\,\eta_B\,\eta_K} \text{ kg combustion air/kg process air,} \tag{83}$$

where a is the excess air factor. This can be written as

$$A = \frac{a}{738}\,Q_1. \tag{84}$$

Therefore when

$$Q_1 = \frac{738}{a}, \tag{85}$$

the process air is just sufficient to burn the necessary fuel. When

$$Q_1 > 738/a, \tag{86}$$

the process air is insufficient for combustion. When

$$Q_1 < 738/a, \tag{87}$$

some of the process air is left over after combustion. This is the case in the usual range of values as can be seen from Table XVII, calculated from equation (83). The extra air can then be used for secondary purposes such as drying the fuel, running an exhaust gas turbine or a secondary expansion motor, or the like.

However, favourable conditions in the heat exchanger require that the water equivalent on both the hot and cold sides be approximately equal. Since the specific heats of hot air and combustion products are nearly the same, the mass flows on both sides should also be the same. Hence as much of the extra air as possible should be led into the heat exchanger, bypassing the combustion chamber. This will of course cool the combustion products and hence the air should be led into the hot side of the combustion chamber at a point where the temperature of the hot gases is equal to the temperature of the air.

4. Part-Load Operations

A hot air engine may be run at part-load by reducing either the mass flow or the temperature at the inlet to the expansion motor, or both simultaneously. The mass flow may be reduced by throttling the compressor inlet or by bleeding off the compressed air after the heat exchanger and using it for secondary purposes. The temperature may be reduced by reducing the fuel feed or by increasing the proportion of the secondary air to the combustion chamber. Part-load conditions can also be obtained by increasing the cut-off ratio or by changing the speed but in most applications, these will be found impracticable.

In the first instance, it may be assumed that the full load mass flow M_1 is reduced to M_1/d_1 by throttling the comprossor inlet and that the full load temperature T_3 is reduced to T_3/d_2 at some part-load. This ensures that the same weight of air is passing through all the components of the power plant. Assuming that the compressor and expansion motor are not coupled the expansion motor output is reduced to $\eta_e L_e/d_1 d_2$ and the compressor input is reduced to $L_c/\eta_c d_1$, while the heat input into the engine is reduced to

$$\frac{1}{\eta_B \, \eta_R} \, C_p \cdot J\left(\frac{T_3}{d_2} - T_2\right). \tag{88}$$

Hence η_d the overall thermal efficiency at part-load equivalent to $1/d$ full load (where $d = d_1 d_2$) is given by

$$\eta_d = \frac{\eta_L \, \eta_M \left(\dfrac{\eta_e \, L_e}{d_1 \, d_2} - \dfrac{L_c}{\eta_c \, d_1}\right)}{\dfrac{1}{\eta_B \, \eta_R} C_p \, J\left(\dfrac{T_3}{d_2} - T_2\right)}. \tag{89}$$

When $d = d_1 = d_2 = 1$, this expression reduces itself to the expression (12) for the full load thermal efficiency. By substituting the usual expressions for L_e and L_e respectively and the relevant numerical values, the equation (89) can be simplified to the form

$$\eta_d = \frac{1}{d_1} \cdot \frac{0 \cdot 1513}{C_p} \frac{E^{0.3} - 1}{E^{0.3}} \frac{T_3 - 420\, d_2\, E^{0.3}}{T_3 - 303\, d_2\, E^{0.3}}. \tag{90}$$

Table XVIII gives these numerical values. By differentiating η_d with respect to $1/d_2$ and equating to zero, it is found that η_d is a maximum when

$$\frac{1}{d_2} = \frac{642\, E^{0.3}}{T_3}. \tag{91}$$

This shows that if part-load conditions are obtained by reducing the temperature T_3 alone and keeping the mass flow constant, then the cut-off ratio should be correspondingly increased. On the other hand, η_d is directly proportional to $1/d_1$. Hence if the mass flow alone is reduced, the efficiency falls proportionately but can be increased again by decreasing the temperature.

The specific output under part-load conditions can be easily obtained as

$$Ls_d = \frac{1}{d} \frac{\eta_L\, \eta_M\, R}{76 \cdot 04} \frac{n}{n-1} (E^{n-1} - 1) \left(\frac{\eta_e\, T_3}{E^{n-1}\, d_2} - \frac{T_1}{\eta_c} \right) \tag{92}$$

or

$$Ls_d = \frac{1 \cdot 083}{d_1\, d_2} \frac{E^{0.3} - 1}{E^{0.3}} (T_3 - 420\, d_2\, E^{0.3}). \tag{93}$$

5. Conclusions

The following broad generalisations can be made regarding the exhaust heated Hot Air Engine cycle applied to low-output reciprocating units, on the basis of the calculations and analysis presented in the two parts of this Report:

(*a*) In its simple form both the efficiency and specific output are rather low, the optimum conditions being a compression ratio in the range of 5 to 7 and a value of $T_3 < 800°$ C.

(*b*) The efficiency can be increased by introducing two or three stage compression and expansion processes. Taking into account the inevitably imperfect reheat and intercooling processes, the increase in efficiency is appreciable only at low values of T_3 and at high compression ratios. The increase in initial cost due to the necessity of reheaters, intercoolers and multiple cylinders of different sizes, as well as due to the higher pressures for which the heat exchanger and the piping system has to be designed, makes the multistage hot air engine cycle *for low output engines*, largely a matter of theoretical interest only.

(*c*) Apart from the proper design of the engine as a whole, the efficiency of the unit depends to a large extent on the efficiencies of the combustion chamber and heat exchanger.

Though a combustion chamber efficiency of 0·98 has been assumed in the calculations, the actual value may be much lower, particularly for furnaces designed for low grade fuels. This will reduce the values of the efficiency indicated in the tables.

The heat exchanger efficiency is also a matter of critical interest to the hot air engine designer. The efficiency can be increased by all the usual methods such as extended surfaces, modern techniques of baffle and header design, etc. The temperature of the metal surfaces at the hot end of the heat exchanger can be kept down by a judicious combination of cross, parallel and counter flow arrangements.

Apart from these considerations, there is another factor which is present in the heat exchanger of a reciprocating hot air engine. This is the presence of pulsations in the tubes resulting from the intermittent operation of the compressor outlet valve. The effect of these pulsations can be for the better or for the worse depending upon the frequency, amplitude, flow velocity and wave velocity employed. It is shown in Part III of this Report that an increase in heat transfer coefficient of at least upto 30%, can be obtained which can be taken advantage of in the hot air engine by correspondingly reducing the heat transfer area and hence the total weight of the heat exchanger. The various findings can be incorporated into the hot air engine with the help of the design of the compressor, expansion motor and the heat exchanger headers.

The hot air engine efficiency is also increased slightly by the fact that heating takes place for part of a cycle at constant pressure, and for the remaining part at constant volume. It has been shown above that this advantage can be materialized by adjusting the phase difference between the compressor and expansion motor in such a way that in each cycle, the expansion motor inlet period precedes the compressor discharge period by a time interval determined by the length of the heat exchanger.

(*d*) While the efficiency of the power plant is low, its weight is at the same time high for a given power. Some methods of reducing the weight have been indicated in sub-section (*c*) above. Another suggestion to reduce the weight is the so-called ' two-stroke ' version of the hot air engine in which compression and expansion occur during alternative strokes of the piston in one and the same cylinder. In this version, it is possible to make provision for the larger volume required for expansion by designing the kinematic linkage of the connecting rod to give alternatively long and short strokes. While attractive from a number of points of view, it suffers from the disadvantage that the cylinder wall temperature remains essentially the same for both compression and expansion. Thus expansion occurs far below the adiabatic line, while compression occurs far above the isothermal line. The result is a considerable drop in output. At the same time, the practical limits in the design of the kinematic linkage also limit the value of T_3 to less than 450 or 500° C. Thus at the present moment this suggestion does not seem to be practicable. The application of a stepped piston of constant stroke but with different swept volume may, on the other hand, show considerable promise.

(*e*) Assuming a simple cycle, it can be seen that the expansion and compression cylinders will have to be of different sizes in order to give maximum efficiency. Ease of manufacture can be promoted by designing the cylinders to be of the same size. It has been shown above that this can be done by separating the expansion process into two parts:—

(1) "Necessary Expansion" to produce the power required to run the compressor and overcome the losses in the unit. (2) "Useful Expansion" to produce useful power. In the range of compression ratios considered to be economical, all the three cylinders can be of the same size, if the temperature is limited to about 700° C.

(*f*) The analysis for part-load conditions shows that provision should be made for the control of the cut-off ratio and furnace temperature. The provision of speed control on the compressor introduces more complexities and also interferes with the heat transfer process in the heat exchanger.

The position may be summarized as follows:—

The efficiency of the cycle, in its most practicable form, is low and the weight of the unit is rather high. In general, the methods which improve efficiency by improving the compression and expansion process result also in increased weight of the unit as a whole. Efforts must be concentrated therefore on improving and reducing the weight of the heat exchanger and combustion chamber. In this connection, the utilisation of the pulsations present in the system is recommended both in the heat exchanger and combustion chamber.

When compared with a steam engine, the efficiency is higher but the weight is greater because of the presence of a compressor in place of a feed pump and because the air-to-air heat exchanger is bulkier than an air-to-water heat exchanger. The most important advantage of the hot air engine is that it requires no water and hence is of greater versatility and suitability in areas where water is scarce.

Compared with a closed cycle hot air engine, the cycle described here requires no cooler and is free from the danger of contamination of the working medium with lubricating oil.

Compared with internal combustion engines, the main consideration is that it is capable of accepting low-grade, cheap and locally available fuels (for which the only modifications necessary for different local conditions may concern the furnace). In fact, because of this, the efficiency or the fuel costs in relation to the output become a comparatively minor consideration.

6. SUGGESTIONS FOR FUTURE WORK

It is suggested that further fundamental data on the cycle may be investigated in order to make it not only practicable but to allow a design to be made which fulfils to a large extent reasonable operational expectations. This implies work along the following lines:—

(1) Building of a practicable heat exchanger making use of the pulsations present to increase the heat transfer coefficient.

(2) Studying the effect of pulsations on furnace efficiency and incorporating the results in a practical furnace.

(3) Determining the cheapest and indigenous materials that can be used in view of the fact that no objectionable gases come into contact with the stationary or especially with the moving parts of the piston-cylinder assembly.

(4) To limit the temperature of the products of combustion, and to ensure its completeness it will be necessary to admit secondary air. This can be done by an ejector working with the exhaust air of the expansion motor as pulsating forcing medium. Its design has to be investigated especially in view of the counter pressure of the combustion apparatus and the heat exchanger.

(5) Determining the best integrated design with a view to improve the ease of maintenance, operation and transportation, and to lower initial costs.

(6) Determining the cheapest and easiest starting system.

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8. LIST OF REFERENCES

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9. List of Symbols and Units

Symbol	Significance	Units
a	Air-fuel ratio	..
B	Calorific value	kcal/kg
d	Ratio of full load to part-load	..
d_1	Ratio of full load mass flow to part-load mass flow	..
d_2	Ratio of full load temperature to part-load temperature	..
F	Amount of fuel necessary	kg/kg

Note.—Other symbols used have the same significance as in Part I.

10. List of Tables

TABLE XI

Values of η for two-stage compression

E	T_3 = 600	700	800	900	1000	1100	1200° K
2	4·9284	6·8862	7·6477	8·2051	8·5727	8·8507	9·0090
3	4·7311	8·2909	10·1788	11·3212	12·0588	12·5238	12·8602
4	3·5746	8·7781	10·7955	13·0846	14·0745	14·7534	15·2384
5	0·6369	7·7898	11·4122	13·5458	14·8802	15·8139	16·4565
6	..	6·9913	11·3759	13·9420	15·5883	16·6348	17·4635
7	..	5·6921	10·9433	13·9406	15·8443	17·1521	18·0885
8	..	4·2046	10·2709	13·7193	15·9392	17·4591	18·5007
9	..	2·9922	9·7696	13·5862	15·9997	17·6775	18·8898
10	..	1·3214	8·9354	13·2083	15·9045	17·7133	18·9989
11	..	..	8·2370	12·8925	15·8416	17·7912	19·2096
12	..	..	7·4122	12·4589	15·6579	17·7349	19·2199
13	..	..	6·6576	12·0924	15·4709	17·6379	19·3722
14	..	..	5·7257	11·5833	15·2507	17·6302	19·3208

TABLE XII

Values of L_s for two-stage compression

E	$T_3 = 600$	700	800	900	1000	1100	1200° K
2	23·0274	43·3741	63·7208	84·0675	104·4141	124·7608	145·1075
3	20·4161	50·8331	81·2501	115·7346	142·0842	172·5013	202·9183
4	14·4909	51·5746	87·0593	125·7418	162·8255	199·9091	236·9928
5	2·4368	38·2370	85·4929	127·0210	168·5490	210·0770	251·6051
6	..	30·3553	83·3206	128·4041	173·4877	218·5713	263·6548
7	..	21·6833	78·3006	126·2459	174·1912	222·1365	270·0819
8	..	15·0860	71·9917	122·3001	172·6086	222·9170	273·2255
9	..	6·5159	67·4107	119·7354	172·0601	224·3847	276·7094
10	..	..	60·5750	114·6341	168·6932	222·7522	276·8113
11	..	..	54·8797	110·4780	166·0764	221·6747	277·2731
12	..	..	48·7843	105·7594	162·7344	219·7095	276·6845
13	..	..	43·1887	101·3775	159·5670	217·7561	275·9452
14	..	..	36·6392	95·9232	155·2071	214·4911	273·7750

TABLE XIII

Values of η for two-stage compression and expansion

E	Reheat Factor	$T_3 = 600$	700	800	900	1000	1100	1200° K
2	1·9009	10·9002	11·3167	11·0112	10·9187	10·9027	10·9121	10·7672
	2·0	12·2675	12·4978	12·0326	11·8508	11·7776	11·7468	11·5600
3	1·8474	15·3360	15·7677	15·9183	16·0170	16·0271	15·9329	15·8544
	1·9	15·1888	16·5691	16·7884	16·8113	16·7670	16·6291	16·5177
	2·0	18·8430	18·6462	18·4425	18·3213	18·1737	17·9528	17·7786
4	1·8123	17·5036	18·3390	18·7176	18·9204	19·3029	18·8579	18·7816
	1·9	20·0864	20·4633	20·5642	20·5938	20·3768	20·3076	20·3076
	2·0	23·1602	22·8856	22·6696	22·5019	22·1314	21·9606	21·9606
5	1·7849	18·6691	20·0237	20·6227	20·9496	20·9854	21·7986	20·9745
	1·8	19·2209	20·4600	20·9981	21·2878	21·2959	21·3719	21·2504
	1·9	22·8754	23·3500	23·4847	23·5271	23·3523	23·3059	23·0777
	2·0	26·5299	26·2400	25·9713	25·7664	25·4088	25·2399	24·9049
6	1·7645	19·1160	21·0006	21·8501	22·2905	22·4688	22·4499	22·5144
	1·8	20·6028	22·1595	22·8401	23·1772	23·2830	23·2082	23·2342
	1·9	24·7907	25·4239	25·6290	25·6748	25·5765	25·3442	25·2616
	2·0	28·9786	28·6883	28·4179	28·1724	27·8700	27·4803	27·2891
7	1·7468	19·2207	21·6705	22·8015	23·3068	23·5306	23·7129	23·7491
	1·8	21·7284	23·5950	24·4351	24·7585	24·8576	24·9541	24·9220
	1·9	26·4422	27·2125	27·5060	27·4873	27·3519	27·2871	27·1265
	2·0	31·1560	30·8300	30·5768	30·2161	29·8462	29·8189	29·3311
8	1·7315	19·1306	22·0980	23·4740	24·0810	24·4639	24·7494	24·7456
	1·8	22·7264	24·8023	25·7508	26·0923	26·3029	26·4691	26·3631
	1·9	27·9756	28·7502	29·0748	29·0286	28·9875	28·9797	28·7244
	2·0	33·2249	32·6981	32·3987	31·9648	31·6721	31·4902	31·0856
9	1·7194	18·6090	19·5658	23·8794	24·6357	25·0316	25·3290	25·5570
	1·8	23·1630	25·7107	26·7229	27·1405	27·3104	27·4529	27·5678
	1·9	28·8132	29·9357	30·2508	30·2484	30·1376	30·0881	30·0627
	2·0	34·4634	34·1607	33·7788	33·3562	32·9648	32·7232	32·5576

TABLE XIII—*Contd.*

E	Reheat Factor	$T_3 = 600$	700	800	900	1000	1100	1200° K
10	1·7077	18·0304	22·3594	24·2108	25·1645	25·6803	25·9664	25·6308
	1·8	23·6779	26·5157	27·6598	28·1981	28·4369	28·5244	28·5090
	1·9	29·7967	31·0188	31·3965	31·4846	31·4234	31·2957	31·1162
	2·0	35·9155	35·5219	35·1331	34·7712	34·4099	34·0671	33·7233
11	1·6978	17·3346	22·3345	24·4837	25·5506	26·1957	26·5105	26·7043
	1·8	24·0268	27·1968	28·5002	29·0679	29·3906	29·4680	29·4856
	1·9	30·5749	31·9544	32·4302	32·5094	32·5167	32·3618	32·2070
	2·0	37·1231	36·7120	36·3602	35·9510	35·6429	35·2555	34·9284
12	1·6887	16·4828	24·9785	24·5822	25·7750	26·5177	26·9006	27·0507
	1·7	17·2771	22·7457	25·0454	26·1791	26·8842	27·2396	27·3682
	1·8	24·2440	27·7401	29·1446	29·7555	30·1280	30·2396	30·1781
	1·9	31·2109	32·7346	33·2437	33·3320	33·3718	33·2396	32·9880
	2·0	38·1778	37·7291	37·3428	36·9082	36·6155	36·2395	35·7979
13	1·6807	15·6094	22·0519	24·7150	26·0366	26·8218	27·2602	27·5912
	1·7	17·0331	23·0616	25·5390	26·7531	27·4695	27·8584	28·1540
	1·8	24·4092	28·2935	29·8083	30·4657	30·8253	30·9583	31·0701
	1·9	31·7852	33·5253	34·0777	34·1782	34·1812	29·9182	33·9863
	2·0	39·1613	38·7572	38·3470	37·8908	37·5370	37·1582	36·9024
14	1·6729	14·5781	21·7876	24·7358	26·2748	27·1258	27·6368	27·9310
	1·7	16·6930	23·2670	25·9364	27·3186	28·0668	28·5054	28·7450
	1·8	24·4973	28·7263	30·3667	31·1702	31·5390	31·7104	31·7489
	1·9	32·3016	34·1855	34·7971	35·0219	35·0111	34·9154	34·7527
	2·0	40·1059	39·6448	39·2275	38·8736	38·4833	38·1205	37·7565

TABLE XIV

Values of L_s for two-stage compression and expansion

E	Reheat Factor	T_3 = 600	700	800	900	1000	1100	1200° K
2	1·9009	23·4178	43·8376	64·2508	84·6641	105·0773	125·4905	145·9038
	2·0	29·8095	51·2870	72·7644	94·2419	115·7194	137·1968	158·6743
3	1·8474	21·1278	51·6705	82·2130	112·7557	142·7602	173·8409	204·3836
	1·9	26·3455	56·5872	89·1701	120·5823	151·9946	183·4069	214·8191
	2·0	36·2652	69·3307	102·3963	135·4618	168·5274	201·5438	234·6585
4	1·8123	13·0784	49·9528	86·8149	123·6771	160·5392	197·4013	234·2637
	1·9	23·7835	62·4395	101·0855	139·7315	178·3774	217·0234	255·6694
	2·0	35·9975	76·6775	117·3575	158·0375	198·7174	239·3974	280·0774
5	1·7849	2·8456	44·4544	86·0629	127·6717	169·2805	210·8893	252·4981
	1·8	4·9575	46·9183	88·8790	130·8398	172·8005	214·7613	256·7220
	1·9	18·9444	63·2363	107·5283	151·8202	196·1121	240·4040	284·6959
	2·0	32·9314	79·5544	126·1775	172·8005	219·4236	265·7497	312·6697
6	1·7645	..	37·8215	82·8633	127·5712	172·9468	217·9886	263·0304
	1·8	..	44·1650	90·1129	136·0609	182·0089	227·9569	273·9048
	1·9	13·5330	62·0336	110·5343	159·0349	207·5355	256·0362	304·5368
	2·0	28·8490	79·9023	130·9556	182·0089	233·0622	284·1155	335·1688
7	1·7468	..	30·1927	78·1334	126·0742	174·0149	221·9557	269·8964
	1·8	..	40·4132	89·8141	139·2149	188·6157	238·0165	287·4173
	1·9	7·4794	59·6247	111·7700	163·9159	216·0606	268·2059	320·3312
	2·0	23·9463	78·8361	133·7259	188·6157	243·5055	298·3953	353·2851
8	1·7315	..	22·1236	72·5086	122·8935	173·2785	223·6634	274·0488
	1·8	..	36·0765	88·4548	140·8331	193·2115	245·5898	297·9681
	1·9	1·1576	56·4458	111·7341	167·0223	222·3105	277·5988	332·8870
	2·0	18·6170	76·8152	135·0133	193·2115	251·4096	309·6077	367·8059
9	1·7194	..	14·7367	67·0345	119·3323	171·6297	223·9161	276·2254
	1·8	..	31·8977	86·6469	141·3962	196·1454	250·8946	305·6438
	1·9	..	53·1891	110·9799	168·7708	226·5616	284·3524	342·1433
	2·0	13·6480	74·4804	135·3129	196·1454	256·9778	317·8103	378·6428

TABLE XIV—*Contd.*

E	Reheat Factor	$T_3 = 600$	700	800	900	1000	1100	1200° K
10	1·7077	..	6·7057	60·8115	114·9179	169·0242	223·1305	278·2551
	1·8	..	27·4763	84·2070	141·2377	198·2684	255·2991	312·3298
	1·9	..	49·3549	109·5540	169·7531	229·9522	290·1512	350·3503
	2·0	8·1660	71·5335	134·9010	198·2684	261·6359	325·0033	388·3708
11	1·6978	..	..	54·8165	110·4273	166·0385	221·6493	277·2605
	1·8	..	22·6382	81·5967	140·5553	199·5138	258·4723	317·4308
	1·9	..	45·5665	107·8005	170·0345	232·2685	294·5025	356·7365
	2·0	2·9854	68·4948	134·0043	199·5138	265·0232	330·5327	396·0422
12	1·6887	..	..	48·7089	105·6964	161·2539	219·6709	276·6584
	1·7	..	4·9515	51·7597	109·1284	166·4971	223·8658	281·2345
	1·8	..	18·0134	78·7567	139·5001	200·2434	260·9867	321·7301
	1·9	..	41·6358	105·7538	169·8717	233·9897	298·1077	362·2256
	2·0	..	65·2582	132·7508	200·2434	267·736	335·2286	402·7212
13	1·6807	..	..	42·8286	100·9921	159·1556	217·3196	275·4831
	1·7	..	..	48·1719	107·0035	165·8350	224·6665	283·4981
	1·8	..	13·5651	75·8573	138·1496	200·4418	262·7340	325·0262
	1·9	..	37·7899	103·5428	169·2957	235·0486	249·9615	366·5544
	2·0	..	62·0146	131·2282	200·4418	269·6554	338·8689	408·0825
14	1·6729	..	..	36·6421	95·9435	155·2448	214·5467	273·8480
	1·7	..	..	44·3271	104·5893	164·8515	225·1138	285·3760
	1·8	..	8·8787	72·6858	136·4928	200·2999	264·1070	327·9140
	1·9	..	33·6925	101·0445	168·3964	235·7483	303·1002	370·4521
	2·0	..	58·5064	129·4032	200·2999	271·1966	342·0934	412·9901

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TABLE XV

Values of η for three-stage expansion and compression

E	Reheat Factor	T_3 = 600	700	800	900	1000	1100	1200° K
2	2·8031	10·4348	10·6063	10·6076	10·6095	10·4605	10·4745	10·5177
	2·9	11·2808	11·3277	11·2512	11·2033	11·0118	11·0148	11·0275
	3·0	12·1540	12·0721	11·9154	11·8162	11·5809	11·5453	11·5536
3	2·6987	14·5440	14·9826	15·2079	15·3164	15·3337	15·3121	15·2139
	2·8	15·9820	16·1835	16·2754	16·2967	16·2505	16·1808	16·0417
	2·9	17·4013	17·3691	17·3291	17·2645	17·1556	17·0383	16·8589
	3·0	18·8206	18·5545	18·3829	18·2322	18·0605	17·8958	17·6762
4	2·6285	16·5876	17·5338	17·9511	18·0785	18·1781	18·2654	18·2672
	2·7	17·8982	18·6228	18·9121	18·9521	18·9933	19·0389	19·0064
	2·8	19·7311	20·1458	20·2557	20·1741	20·1334	20·1207	20·0404
	2·9	21·5640	21·6688	21·5996	21·3960	21·2735	21·2025	21·0743
	3·0	23·3970	23·1920	22·9433	22·6180	22·4137	22·2843	22·1083
5	2·5764	17·5860	18·9582	19·5942	19·8892	20·0655	20·2876	20·2815
	2·6	18·0949	19·3777	19·9624	20·2240	20·3771	20·5840	20·5637
	2·7	20·2518	21·1544	21·5228	21·6422	21·6974	21·8395	21·7597
	2·8	22·4086	22·9314	23·0834	23·0604	23·0177	23·0950	22·9555
	2·9	24·5650	24·7081	24·6438	24·4786	24·3379	24·3506	24·1514
	3·0	26·7219	26·4850	26·2042	25·8969	25·6582	26·6060	25·3473
6	2·5349	18·1756	19·6426	20·8445	21·2589	21·4628	21·7577	21·6926
	2·6	19·7727	20·9354	21·9852	22·2926	22·4208	22·6678	22·5548
	2·7	22·2255	22·9207	23·7377	23·8803	23·8925	24·0659	23·8792
	2·8	24·6789	24·9066	25·4902	25·4681	25·3641	25·4638	25·2036
	2·9	27·1322	26·8919	27·2428	27·0559	26·8356	26·8617	26·5280
	3·0	29·5855	28·8776	28·9953	28·6439	28·3071	28·2598	27·8524
7	2·5012	18·2882	20·4955	21·6241	22·1391	22·5098	22·6810	22·7992
	2·6	20·9445	22·6490	23·5055	23·8382	24·0886	24·1671	24·2153
	2·7	23·6330	24·8286	25·4100	25·5583	25·6866	25·6712	25·6485
	2·8	26·3214	27·0081	27·3145	27·2781	27·2845	27·1754	27·0818
	2·9	29·0104	29·1876	29·2191	28·9889	28·8827	30·1836	28·5151
	3·0	31·6989	31·3672	31·1236	30·7180	30·4807	30·1836	29·9483

TABLE XV—*Contd.*

E	Reheat Factor	T_s = 600	700	800	900	1000	1100	1200° K
8	2·4719	18·2898	20·9331	22·2525	23·0439	23·3796	23·5593	23·8525
	2·5	19·1112	21·5947	22·8281	23·5656	23·8614	24·0113	24·2852
	2·6	22·0356	23·9487	24·8749	25·4226	25·5753	25·6196	25·8254
	2·7	24·9600	26·3031	20·2822	27·2796	27·2895	27·2281	27·3658
	2·8	27·8682	28·6571	28·7929	29·1368	29·0034	28·8365	28·9059
	2·9	30·8088	31·0115	31·0165	30·9938	30·7176	30·4450	30·4461
	3·0	33·7338	33·3655	33·0633	32·5084	32·4315	32·0535	31·9863
9	2·4467	18·1439	21·3544	22·7483	23·5938	24·1483	24·4475	24·6161
	2·5	19·8110	22·6012	23·9042	24·6372	25·1157	25·3570	25·4801
	2·6	22·9511	25·1180	26·0806	26·6019	26·9376	27·0698	27·1078
	2·7	26·0904	27·6349	28·2573	28·5665	28·7593	28·7824	28·7354
	2·8	29·2298	30·1517	30·4337	30·5312	30·5812	30·4951	30·3630
	2·9	32·3692	32·6686	32·6104	32·4958	32·4031	32·2077	31·9907
	3·0	35·5092	35·1855	34·7868	34·4605	34·2248	33·9205	33·6183
10	2·4252	17·8783	21·3887	23·0771	24·0094	24·7336	24·9879	25·1256
	2·5	20·3703	23·3725	24·7882	25·5493	26·1654	26·3275	26·3946
	2·6	23·7017	26·0246	27·0756	26·6083	28·0796	28·1186	28·0912
	2·7	27·0331	28·6768	29·3634	27·6669	29·9939	29·9099	29·7878
	2·8	30·3639	31·3289	31·6508	31·7258	31·9082	31·7010	31·4843
	2·9	33·6953	33·9810	33·9383	33·7844	33·8224	33·4921	33·1810
	3·0	37·0267	36·6331	36·2257	35·8433	35·7364	35·2832	34·8775
11	2·4061	17·5199	21·4676	23·3472	24·4325	25·1229	25·5377	25·7861
	2·5	20·8166	24·0819	25·5953	26·4559	26·9941	27·2948	27·4546
	2·6	24·3243	26·8630	27·9874	28·6085	28·9844	29·1643	29·2295
	2·7	27·8320	29·6445	30·3791	30·7612	30·9750	31·0336	31·0044
	2·8	31·3390	32·4255	32·7708	32·9138	32·9656	32·9031	32·7795
	2·9	34·8467	35·2071	35·1625	35·0664	34·9563	34·7723	34·5544
	3·0	38·3544	37·9881	37·5546	37·2190	36·9469	36·6418	36·3295

TABLE XV—*Contd.*

E	Reheat Factor	$T_3 = 600$	700	800	900	1000	1100	1200° K
12	2·3883	17·0949	21·4556	23·5554	24·6975	25·4219	25·9728	26·3101
	2·5	21·1989	24·6942	26·3364	27·1912	27·7221	28·1390	28·3698
	2·6	24·8727	27·5939	28·8266	29·4236	29·7813	30·0781	30·2139
	2·7	28·5465	30·4932	31·3163	31·6563	31·8405	32·0172	32·0578
	2·8	32·2203	33·3925	33·8061	33·8886	33·9000	33·9565	33·9017
	2·9	35·8941	36·2917	36·2958	36·1210	35·9592	35·8956	35·7458
	3·0	39·5687	39·1915	38·7860	38·3533	38·0184	37·8347	37·5898
13	2·3728	16·6180	21·3220	23·6800	24·9203	25·8482	26·3245	26·5983
	2·5	21·4795	25·1333	26·9564	27·8533	28·5654	28·8693	29·0084
	2·6	25·3015	28·1295	29·5323	30·1591	30·7017	30·8701	30·9031
	2·7	29·1235	31·1256	32·1081	32·4645	32·8379	32·8709	32·7979
	2·8	32·9455	34·1218	34·6840	34·7702	34·9742	34·8717	34·6926
	2·9	36·7675	37·1179	37·2599	37·0760	37·1104	36·8724	36·5874
	3·0	40·5895	40·1141	39·8357	39·3817	39·2466	38·8732	38·4822
14	2·3580	16·1070	21·2554	23·7103	25·1833	26·0563	26·6489	26·8660
	2·4	17·7769	22·5605	24·8249	26·1852	26·9790	27·5147	27·6828
	2·5	21·7536	25·6684	27·4795	28·5698	29·1754	29·5762	29·6276
	2·6	25·7312	28·7757	30·1337	30·9544	31·3722	31·6375	31·5721
	2·7	29·7088	31·8831	32·7884	33·3394	33·5687	33·6991	33·5169
	2·8	33·6846	34·9910	35·4426	35·7241	35·7654	35·7604	35·4617
	2·9	37·6622	38·0983	38·0968	38·1090	37·9619	37·8220	37·4063
	3·0	41·6389	41·2056	40·7514	40·4937	40·1587	39·8833	39·3511

TABLE XVI

Values of L_s for three-stage compression and expansion

E	Reheat Factor	T_s = 600	700	800	900	1000	1100	1200° K
2	2·8031	25·1862	45·5816	65·9779	86·3733	106·7687	127·1650	147·5604
	2·9	29·4161	50·5175	71·6180	92·7186	113·8192	134·9205	156·0211
	3·0	33·7818	55·6109	77·4392	99·2675	121·0958	142·9241	164·7524
3	2·6987	25·7572	56·1540	86·5507	116·9475	147·3443	177·7411	208·1378
	2·8	32·6041	64·1409	95·6791	127·2159	158·7541	190·2922	221·8291
	2·9	39·3617	72·0261	104·6892	137·3536	170·0683	202·6812	235·3460
	3·0	46·1193	79·9100	113·7007	147·4901	181·2808	215·0714	248·7829
4	2·6285	20·4427	57·3890	94·3338	131·2801	168·2249	205·1712	242·1160
	2·7	26·4731	64·4240	102·3749	140·3241	178·2750	216·2259	254·1752
	2·8	34·9066	74·2625	113·6185	152·9744	192·3304	231·6863	271·0422
	2·9	43·3401	84·1011	124·8637	165·6247	206·3857	247·1483	287·9093
	3·0	51·7737	93·9413	136·1074	178·2750	220·4427	262·6087	304·7763
5	2·5764	13·3397	54·7279	96·1181	137·5064	178·8965	220·2848	256·8150
	2·6	15·6142	57·3834	99·1508	140·9200	182·6874	224·4566	266·2240
	2·7	25·2535	68·8164	112·0020	155·3781	198·7523	242·1266	285·5027
	2·8	34·8929	79·8740	124·8551	169·8362	214·8173	259·7984	304·7795
	2·9	44·5303	91·1183	137·7063	184·2943	230·8822	277·4702	324·0563
	3·0	54·1697	102·3645	150·5575	198·7523	246·9472	295·1401	343·3350
6	2·5349	5·4591	48·8814	95·5379	140·5751	185·6145	230·6539	278·6933
	2·6	12·3994	56·9373	104·7901	150·9855	197·1809	243·3763	289·5738
	2·7	23·0584	69·3090	114·0043	166·9761	214·9501	262·9220	310·8939
	2·8	33·7195	81·6850	133·2184	182·9668	232·7173	282·4656	332·2140
	2·9	44·3806	94·0568	147·4325	198·9574	250·4844	302·0093	353·5363
	3·0	55·0418	106·4306	161·6466	214·9501	268·2515	321·5550	374·8464
7	2·5012	..	45·5207	93·3197	141·1186	188·9176	236·7166	284·5155
	2·6	9·0503	58·7378	108·4229	158·1103	207·7978	257·4852	307·1726
	2·7	20·5158	72·1149	123·7117	175·3108	226·9076	278·5067	330·1035
	2·8	31·9812	85·4920	139·0005	192·5090	246·0174	299·5282	353·0367
	2·9	43·4490	98·8691	154·2893	209·6166	265·1296	320·5498	375·9699
	3·0	54·9144	112·2462	169·5781	226·9076	284·2394	341·5713	398·9008

TABLE XVI—*Contd.*

E	Reheat Factor	T_3 = 600	700	800	900	1000	1100	1200° K
8	2·4719	..	39·9714	90·2517	140·5345	190·8148	241·0976	291·3780
	2·5	..	43·9727	94·8265	145·6777	196·5314	247·3852	298·2364
	2·6	5·6390	58·2105	111·0975	163·9845	216·8714	269·7584	322·6454
	2·7	17·5280	72·4507	124·5892	182·2912	237·2139	294·3878	347·0569
	2·8	29·7325	86·6885	142·2422	200·6004	257·5539	314·5099	371·4659
	2·9	41·9370	100·9287	159·9180	218·9072	277·8964	336·8857	395·8749
	3·0	54·1440	115·1665	176·1890	237·2139	298·2364	359·2614	420·2839
9	2·4469	..	34·8470	86·6882	139·0627	191·4373	243·8118	296·1890
	2·5	..	42·2693	95·7826	149·2933	202·8040	256·3147	309·8254
	2·6	1·6029	57·2525	112·9048	168·5571	224·2094	280·1283	335·5113
	2·7	14·4445	72·2357	130·0296	187·8208	245·6120	303·4059	361·1971
	2·8	27·2861	87·2189	147·1517	207·0845	267·0174	326·9502	386·8830
	2·9	40·1277	102·2021	164·2765	226·3483	288·4227	350·4945	412·5689
	3·0	52·9720	117·1853	181·3987	245·6120	309·8254	374·0414	437·4597
10	2·4252	..	28·7539	82·8444	136·9349	191·0254	245·1159	299·2064
	2·5	..	40·4324	96·1908	151·9493	207·7078	263·4662	319·2247
	2·6	..	56·0449	114·0329	172·0237	230·0117	287·9997	345·9905
	2·7	11·4398	71·6574	131·8777	192·0953	252·3156	312·5360	372·7536
	2·8	24·8199	87·2698	149·7198	212·1697	274·6196	337·0695	399·5166
	2·9	38·2028	102·8823	167·5618	232·2413	296·9235	361·6030	426·2825
	3·0	51·5858	118·4948	185·4038	252·3156	319·2247	386·1365	453·0455
11	2·4060	..	23·2396	78·8559	134·4723	190·0886	245·7049	301·3213
	2·5	..	38·4496	96·2371	154·0276	211·8180	269·6056	327·3960
	2·6	..	54·6292	114·7318	174·8316	234·9313	295·0340	355·1337
	2·7	8·3997	70·8117	133·2236	195·6355	258·0475	320·4594	383·8713
	2·8	22·2671	86·9912	151·7154	216·4395	281·1637	345·8878	410·6119
	2·9	36·1374	103·1737	170·2072	237·2435	304·2798	371·3133	438·3496
	3·0	50·0077	119·3533	188·7019	258·0475	327·3960	396·7416	466·0902

TABLE XVI—*Contd.*

E	Reheat Factor	T_3 = 600	700	800	900	1000	1100	1200° K
12	2·3883	..	17·7489	74·7009	131·6497	188·4956	245·5505	302·5024
	2·5	..	36·3936	96·0081	155·6227	215·2373	274·8518	334·4633
	2·6	..	53·0879	115·0869	177·0828	239·0819	301·0809	363·0799
	2·7	5·3956	69·7791	134·1626	198·5460	262·9265	328·3909	391·6934
	2·8	19·7034	86·4703	153·2382	220·0062	286·7741	353·5421	420·3069
	2·9	34·0091	103·1615	172·3139	241·4663	310·6187	379·7711	448·9235
	3·0	48·3189	119·8558	191·3927	262·9265	334·4633	406·0002	477·5370
13	2·3728	..	12·5239	70·6523	128·7775	186·9027	245·0311	303·1564
	2·5	..	34·3371	95·5798	156·8226	218·0622	279·3049	340·5477
	2·6	..	51·4851	115·1775	178·8700	242·5593	306·2517	369·9442
	2·7	2·4909	68·6330	134·7752	200·9142	267·0564	333·1985	399·3407
	2·8	17·1891	85·7810	154·3729	222·9616	291·5535	439·2704	428·7372
	2·9	31·8874	102·9290	173·9706	245·0090	316·0506	387·0922	458·1338
	3·0	46·5856	120·0769	196·7332	267·0564	340·5477	414·0390	487·5303
14	2·3580	..	7·1177	66·4131	125·7052	185·0006	244·2961	303·5882
	2·4	..	14·5104	74·8600	135·2129	195·5626	255·9122	316·2619
	2·5	..	32·1147	94·9787	157·8428	220·7069	283·5742	346·4383
	2·6	..	49·7157	115·0942	180·4727	245·8545	311·2330	376·6115
	2·7	..	67·3167	135·2129	203·1059	270·9988	338·8950	406·7880
	2·8	14·5104	84·9210	155·3284	225·7358	296·1464	366·5538	436·9644
	2·9	29·6002	102·5220	175·4438	248·3689	321·2907	394·2158	467·1376
	3·0	44·6868	120·1231	195·5626	270·9988	346·4383	421·8745	497·3141

TABLE XVII

Amount of air necessary for combustion

a	E	$T_3 = 600$	800	1000	1200° K
1·0	2	0·1192	0·2271	0·3394	0·4556
	3	0·0948	0·2027	0·3150	0·4313
	4	0·0754	0·1831	0·2953	0·4114
	5	0·0592	0·1668	0·2789	0·3950
	6	0·0452	0·1531	0·2655	0·3817
	7	0·0326	0·1405	0·2529	0·3691
	8	0·0211	0·1287	0·2409	0·3569
	9	0·0106	0·1183	0·2305	0·3466
	10	..	0·1086	0·2209	0·3370
	11	..	0·0996	0·2120	0·3280
	12	..	0·0906	0·2027	0·3188
	13	..	0·0761	0·1948	0·3110
	14	..	0·0747	0·1868	0·3029
1·2	2	0·1419	0·2703	0·4040	0·5424
	3	0·1129	0·2413	0·3750	0·5134
	4	0·0897	0·2180	0·3516	0·4898
	5	0·0704	0·1986	0·3321	0·4702
	6	0·0538	0·1823	0·3161	0·4545
	7	0·388	0·1672	0·3010	0·4395
	8	0·0251	0·1533	0·2868	0·4249
	9	0·0126	0·1408	0·2744	0·4126
	10	..	0·1293	0·2629	0·4012
	11	..	0·1186	0·2524	0·3905
	12	..	0·1078	0·2414	0·3796
	13	..	0·0906	0·2319	0·3702
	14	..	0·0890	0·2224	0·3606
1·4	2	0·1703	0·3244	0·4848	0·6508
	3	0·1354	0·2895	0·4500	0·6161
	4	0·1077	0·2616	0·4219	0·5877
	5	0·0845	0·2383	0·3985	0·5642
	6	0·0645	0·2187	0·3793	0·5453
	7	0·0465	0·2007	0·3612	0·5273
1·4	8	0·0301	0·1839	0·3441	0·5099
	9	0·0151	0·1690	0·3293	0·4951
	10	..	0·1551	0·3155	0·4815
	11	..	0·1424	0·3029	0·4686
	12	..	0·1294	0·2896	0·4555
	13	..	0·1088	0·2783	0·4442
	14	..	0·1067	0·2669	0·4327

TABLE XVII—*Contd.*

a	E	T_8 = 600	800	1000	1200° K
1·6	2	0·1930	0·3676	0·5495	0·7376
	3	0·1535	0·3281	0·5100	0·6982
	4	0·1220	0·2964	0·4781	0·6661
	5	0·0958	0·2701	0·4516	0·6395
	6	0·0731	0·2479	0·4298	0·6181
	7	0·0527	0·2274	0·4094	0·5977
	8	0·0341	0·2084	0·3900	0·5779
	9	0·0171	0·1915	0·3732	0·5611
	10	..	0·1758	0·3576	0·5457
	11	..	0·1613	0·3432	0·5311
	12	..	0·1466	0·3282	0·5162
	13	..	0·1233	0·3154	0·5035
	14	..	0·1210	0·3025	0·4903
1·8	2	0·2157	0·4109	0·6141	0·8244
	3	0·1715	0·3667	0·5700	0·7804
	4	0·1079	0·3313	0·5244	0·7445
	5	0·1070	0·3019	0·5048	0·7147
	6	0·0817	0·2770	0·4804	0·6908
	7	0·0589	0·2542	0·4576	0·6680
	8	0·0382	0·2329	0·4359	0·6459
	9	0·0191	0·2141	0·4171	0·6272
	10	..	0·1965	0·3996	0·6099
	11	..	0·1803	0·3836	0·5936
	12	..	0·1639	0·3669	0·5769
	13	..	0·1378	0·3525	0·5627
1·8	14	..	0·1352	0·3381	0·5480
2·0	2	0·2384	0·4541	0·6788	0·9111
	3	0·1896	0·4053	0·6300	0·8625
	4	0·1507	0·3662	0·5906	0·8228
	5	0·1183	0·3336	0·5579	0·7900
	6	0·0903	0·3062	0·5310	0·7635
	7	0·0651	0·2809	0·5057	0·7383
	8	0·0422	0·2575	0·4818	0·7139
	9	0·0211	0·2366	0·4610	0·6932
	10	..	0·2172	0·4417	0·6741
	11	..	0·1993	0·4240	0·6560
	12	..	0·1811	0·4055	0·6376
	13	..	0·1523	0·3896	0·6219
	14	..	0·1494	0·3737	0·6057

TABLE XVII—*Contd.*

a	E	T_s = 600	800	1000	1200° K
2·1	2	0·2611	0·4974	0·7434	0·9979
	3	0·2076	0·4439	0·6900	0·9447
	4	0·1651	0·4011	0·6469	0·9012
	5	0·1296	0·3654	0·6110	0·8652
	6	0·0989	0·3353	0·5815	0·8362
	7	0·0713	0·3077	0·5539	0·8086
	8	0·0462	0·2820	0·5277	0·7819
	9	0·0231	0·2591	0·5049	0·7592
	10	..	0·2379	0·4838	0·7383
	11	..	0·2183	0·4644	0·7185
	12	..	0·1984	0·4441	0·6984
	13	..	0·1668	0·4267	0·6812
	14	..	0·1637	0·4093	0·6634
2·4	2	0·2894	0·5514	0·8242	1·1064
	3	0·2302	0·4922	0·7651	1·0473
	4	0·1830	0·4447	0·7172	0·9991
	5	0·1437	0·4051	0·6774	0·9592
	6	0·1097	0·3718	0·6447	0·9271
2·4	7	0·0791	0·3411	0·6141	0·8965
	8	0·0512	0·3126	0·5850	0·8668
	9	0·0257	0·2873	0·5598	0·8417
	10	..	0·2637	0·5364	0·8185
	11	..	0·2420	0·5148	0·7966
	12	..	0·2200	0·4924	0·7743
	13	..	0·1849	0·4731	0·7552
	14	..	0·1815	0·4537	0·7355
2·6	2	0·3121	0·5947	0·8889	1·1932
	3	0·2483	0·5308	0·8251	1·1295
	4	0·1974	0·4795	0·7734	1·0776
	5	0·1549	0·4369	0·7306	1·0344
	6	0·1183	0·4010	0·6953	0·9998
	7	0·0853	0·3679	0·6623	0·9668
	8	0·0552	0·3372	0·6309	0·9348
	9	0·277	0·3098	0·6037	0·9077
	10	..	0·2844	0·5784	0·8827
	11	..	0·2610	0·5552	0·8591
	12	..	0·2372	0·5310	0·8350
	13	..	0·1994	0·5102	0·8144
	14	..	0·1957	0·4893	0·7932

TABLE XVII—*Contd.*

a	E	$T_3 = 600$	800	1000	1200° K
2·8	2	0·3348	0·6379	0·9535	1·2799
	3	0·2663	0·5694	0·8851	1·2116
	4	0·2118	0·5144	0·8297	1·1559
	5	0·1662	0·4687	0·7837	1·1097
	6	0·1269	0·4301	0·7459	1·0725
	7	0·0915	0·3947	0·7104	1·0371
	8	0·0592	0·3617	0·6768	1·0028
	9	0·0297	0·3323	0·6476	0·9737
	10	..	0·3051	0·6205	0·9469
	11	..	0·2800	0·5956	0·9216
	12	..	0·2545	0·5696	0·8957
	13	..	0·2139	0·5473	0·8737
	14	..	0·2099	0·5249	0·8509

TABLE XVIII

Thermal efficiency at part-load

d_1	T_3, ° K	E	$d_2 = 1 \cdot 000$	1·333	1·500	2·000
1·000	600	2	0·0414	..	..	..
		3	0·0154	..	..	..
	800	2	0·0751	0·0414	0·0115	..
		3	0·0969	0·0155	..	..
		4	0·0981	..	..	..
		5	0·0895	..	..	..
		6	0·0725	..	..	..
		7	0·0489	..	..	..
		8	0·0195	..	..	..
	1000	2	0·0872	0·0700	0·0577	..
		3	0·1221	0·0859	0·0573	..
		4	0·1381	0·0795	0·0282	..
		5	0·1455	0·0621	..	..
		6	0·1470	0·0339	..	..
		7	0·1447	..	..	..
		8	0·1398	..	..	..
		9	0·1326	..	..	..
		10	0·1237	..	..	..
		11	0·1131	..	..	..
		12	0·1009	..	..	..
		13	0·0876	..	..	..
		14	0·0730	..	..	..
	1200	2	0·0935	..	..	..
		3	0·1343	0·1122	0·0969	0·0154
		4	0·1565	0·1227	0·0981	..
		5	0·1698	0·1244	0·0895	..
		6	0·1778	0·1196	0·0725	..
		7	0·1822	0·1104	0·0489	..
		8	0·1843	0·0978	0·0195	..
		9	0·1845	0·0821	..	..
		10	0·1835	0·0636	..	..
		11	0·1813	0·0697	..	..
1·000	1200	12	0·1783	0·0181	..	..
		13	0·1745	..	..	..
		14	0·1701	..	..	..

TABLE XVIII—*Contd.*

d_1	T_3, °K	E	d_2 = 1·000	1·333	1·500	2·000
1·333	600	2	0·0311	..	..	..
		3	0·0116	..	..	..
	800	2	0·0563	0·0311	0·0086	..
		3	0·0727	0·0116	..	..
		4	0·0736	..	..	..
		5	0·0671	..	..	..
		6	0·0544	..	..	..
		7	0·0367	..	..	..
		8	0·0146	..	..	..
	1000	2	0·0654	0·0525	0·0433	..
		3	0·0916	0·0644	0·0430	..
		4	0·1036	0·0596	0·0212	..
		5	0·1092	0·0466	..	..
		6	0·1103	0·0254	..	..
		7	0·1086	..	..	..
		8	0·1049	..	..	..
		9	0·0995	..	..	..
		10	0·0928	..	..	..
		11	0·0848	..	..	..
		12	0·0757	..	..	..
		13	0·0657	..	..	..
		14	0·0548	..	..	..
	1200	2	0·0701	0·0617	0·0563	0·0311
		3	0·1008	0·0842	0·0727	0·0116
		4	0·1174	0·0920	0·0736	..
		5	0·1274	0·0933	0·0671	..
		6	0·1334	0·0897	0·0544	..
		7	0·1367	0·0828	0·0367	..
		8	0·1383	0·0734	0·0146	..
		9	0·1384	0·0616	..	..
1·333	1200	10	0·1377	0·0477	..	..
		11	0·1360	0·0523	..	..
		12	0·1338	0·0136	..	..
		13	0·1309	..	..	..
		14	0·1276	..	..	..
2·000	600	2	0·0207	..	..	..
		3	0·0077	..	..	..

TABLE XVIII—*Contd.*

d_1	T_3. °K	E	$d_2 = 1\cdot000$	1·333	1·500	2·000
	800	2	0·0376	0·0207	0·0058	..
		3	0·0485	0·0078	..	..
		4	0·0491	..	..	..
		5	0·0448	..	..	..
		6	0·0363	..	..	..
		7	0·0245	..	..	..
		8	0·0098	..	..	..
..	1000	2	0·0436	0·0350	0·0289	..
		3	0·0611	0·0430	0·0287	..
		4	0·0691	0·0398	0·0141	..
		5	0·0728	0·0311	..	..
		6	0·0735	0·0170	..	..
		7	0·0724	..	..	..
		8	0·0699	..	..	..
		9	0·0663	0·0350	0·0289	..
		10	0·0619	0·0430	0·0287	..
		11	0·0566	0·0398	0·0141	..
		12	0·0505	0·0311	..	..
		13	0·0438	0·0170	..	..
		14	0·0365	..	..	..
	1200	2	0·0468	0·0412	0·0375	0·0207
		3	0·0672	0·0561	0·0485	0·0077
		4	0·0783	0·0614	0·0491	..
		5	0·0849	0·0622	0·0448	..
		6	0·0889	0·0598	0·0363	..
2·000	1200	7	0·0911	0·0552	0·0245	..
		8	0·0922	0·0489	0·0098	..
		9	0·0923	0·0411	..	..
		10	0·0918	0·0318	..	..
		11	0·0907	0·0349	..	..
		12	0·0892	0·0091	..	..
		13	0·0873	..	..	..
		14	0·0851	..	..	..
4·000	600	2	0·0104	..	..	..
		3	0·0039	..	..	..

TABLE XVIII—*Contd.*

d_1	T_3, ° K.	E	d_2 = 1·000	1·333	1·500	2·000
	800	2	0·0188	0·0104	0·0029	..
		3	0·0242	0·0039	..	..
		4	0·0245	..	..	..
		5	0·0224	..	..	..
		6	0·0181	..	..	..
		7	0·0122	..	..	..
		8	0·0049	..	..	..
	1000	2	0·0218	0·0175	0·0144	..
		3	0·0305	0·0215	0·0143	..
		4	0·0345	0·0199	0–0071	..
		5	0·0364	0·0155	..	..
		6	0·0368	0·0085	..	..
		7	0·0362	..	..	..
		8	0·0350	..	..	..
		9	0·0332	..	..	..
		10	0·0309	..	..	..
		11	0·0283	..	..	..
		12	0·0252	..	..	..
		13	0·0219	..	..	..
		14	0·0183	..	..	..
4·000	1200	2	0·0234	0·0206	0·0188	0·0104
		3	0·0336	0·0281	0·0242	0·0039
		4	0·0391	0·0307	0·0245	..
		5	0·0425	0·0311	0·0244	..
		6	0·0445	0·0299	0·0181	..
		7	0·0456	0·0276	0·0122	..
		8	0·0461	0·0245	0·0049	..
		9	0·0461	0·0205	..	..
		10	0·0459	0·0159	..	..
		11	0·0453	0·0174	..	..
		12	0·0446	0·0045	..	..
		13	0·0436	..	..	..
		14	0·0425	..	..	..

ABSTRACTS

DEPARTMENT OF METALLURGY

1. VERMICULITE AND ITS BENEFICIATION—A REVIEW. N. R. Srinivasan and R. K. Rama Murthy, *The Eastern Metals Review*, 1955, **8**, 113.

Vermiculite possesses excellent insulating and other properties and is finding increasing use in industry. It comprises a group of nineteen members mostly hydrated magnesium silicates and their mode of origin from phlogopite and biotite is discussed. In addition to listing the major occurrences of vermiculite in the world and in India, attention has been focussed on the possible geological formations in India which may be probed in exploring hidden resources of the versatile mineral. The industrial uses of vermiculite and methods of grading are mentioned. The ore-dressing processes applied for the beneficiation of low grade vermiculite are reviewed and interesting possibilities for the flotation of vermiculite samples in India are indicated.

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