pression, calculate the square root of the total compression ratio. Then assume that the compression ratio per stage will be equal to the square root of the total compression.[2]

Mechanical losses. After the gas power is calculated by either the polytropic or adiabatic compression method, power losses due to friction in bearings, seals and speed-increasing gears should be added. Although there is no accurate method to estimate mechanical losses from gas power requirements, Table 2 gives approximate mechanical losses as a percentage of the gas power requirement.[5]

The mechanical losses can be calculated by:

$$\textit{Mechanical losses} = (\textit{Power})(\%\ \textit{Mechanical losses}) \quad (58)$$

The total power required is:

$$P_{TOTAL} = \textit{Power} + \textit{Mechanical losses} \quad (59)$$

Design problem. A centrifugal compressor is to be specified for a gas plant. The unit is to compress 8,200 kg/hr of gas mixture at 66°C from 1.5 bara to 5.5 bara. The gas mixture consists of 30% hydrogen (H_2), 45% methane (CH_4), 15% ethane (C_2H_6), 7% propane (C_3H_8) and 3% n-butane (n-C_4H_{10}). Assuming a polytropic efficiency of 87%, adiabatic efficiency is 85%, suction compressibility factor $Z_1 = 0.97$ and discharge compressibility factor $Z_2 = 0.93$, calculate the adiabatic head, discharge temperature, actual work required and the total brake power. Table 3 gives the properties of the gas mixture.

The mixture specific heat ratio, k, is defined by:

$$k = \frac{MC_p}{MC_v} = \frac{MC_p}{MC_p - 8.314}$$

$$k = \frac{43.34}{35.026} = 1.237$$

The average molecular weight of the gas mixture: $M_w = 17.162$.

Conversions:

14.5 psi = 1 bar

$$1\,\frac{\text{Btu}}{\text{lb}\,°\text{F}} = 4.2\,\frac{\text{kJ}}{\text{kg K}}$$

Solution. A computer program has been developed for either adiabatic or polytropic compression using the equations described in this article. (The program is available from the author for a nominal fee to cover postage and handling. Contact Dr. A. K. Coker, A.K.C. Technology, 131 George Frederick Road, Sutton Coldfield, West Midlands, B736TE U.K.) Table 4 gives the results of the gas mixture. The results show that:

$$\text{The adiabatic head} = 230.3\ \frac{\text{kJ}}{\text{kg}}$$

The discharge temperature = 162°C

$$\text{The actual work required} = 276.6\ \frac{\text{kJ}}{\text{kg}}$$

Total brake power = 649 kW.

Multicomponent gas streams. Designing a gas compressor for a gas mixture involves estimating the thermodynamic properties. The procedure for calculating gas mixture properties is to use the weighted molal average of the property. These thermodynamic properties are estimated as:

Molecular weight $$M_{w,\,mixture} = \sum_{i=1}^{n} y_i M_i \quad (60)$$

Reduced temperature $$T_{r,\,mixture} = \sum_{i=1}^{n} y_i T_{r,i} \quad (61)$$

Reduced pressure $$P_{r,\,mixture} = \sum_{i=1}^{n} y_i P_{r,i} \quad (62)$$

Molal heat capacity $$MC_{p,\,mixture} = \sum_{i=1}^{n} y_i MC_{p,i} \quad (63)$$

Ratio of molal heat capacities

$$k_{mixture} = \frac{MC_{p,\,mixture}}{MC_{y,\,mixture}} = \frac{MC_{p,\,mixture}}{(MC_{p,\,mixture} - 8.314)} \quad (64)$$

Compressibility factor $Z_{mixture} = f(T_r, P_r)$ (65) for the mixture.

The compressibility Z factor for natural gas is deter-

Table 3. Properties of the gas mixture

Gas	Mole fraction, y	Molecular weight, M_w	yM_w	P_c, psia	T_c, °R	MC_p, $\frac{\text{kJ}}{\text{kg K}}$	yMC_p, 66°C
H_2	0.30	2.01	0.603	188.1	60.2	29.15	8.75
CH_4	0.45	16.04	7.218	666.0	343	37.59	16.92
C_2H_6	0.15	30.07	4.511	707	550	57.88	8.68
C_3H_8	0.07	44.09	3.086	616	660	81.98	5.74
nC_4H_{10}	0.03	58.12	1.744	551	765	108.40	3.25
		M_w =	17.162			MC_p =	43.34

Table 4. Adiabatic compressor sizing

Gas flowrate, kg/hr:	8,200.000
Suction temperature, °C:	66.000
Suction pressure, bara:	1.500
Suction density, kg/m³:	0.941
Suction volumetric rate, m³/hr:	8,712.212
Suction compressibility factor, Z_1:	0.970
Discharge temperature, °C:	161.863
Discharge pressure, bara:	5.500
Discharge density, kg/m³:	2.806
Discharge volumetric rate, m³/h:	2,921.988
Discharge compressibility factor, Z_2:	0.930
Compression ratio, R_c:	3.667
Ratio of specific heats capacities, k:	1.237
Polytropic exponent, n:	1.282
Molecular weight of gas, kg/kg-mole, M_w:	17.162
Average compressibility factor, Z_{az}:	0.950
Adiabatic efficiency, %:	85.000
Polytropic efficiency, %:	87.000
Adiabatic head, kJ/kg:	230.270
Adiabatic work done, kJ/kg:	235.118
Actual work done, kJ/kg:	276.609
Power demand by the compressor, kW:	630.054
Power losses due to friction in bearings, kW:	18.902
Total brake power, kW:	648.956
Calculated adiabatic efficiency from polytropic efficiency, %:	85.326