

A. Heavy Vapour Turbine, Vapour Turbines.

The character of the working fluid, as its vapour density, latent heat of evaporation etc., have no direct effect on the efficiency of a thermodynamic engine, as a turbine.

For instance, a fluid of low latent heat of evaporation, while requiring less energy, gives a correspondingly lower volume of vapour, and so lower available energy, and the latent heat is merely the thermal equivalent of the volume change at evaporation, and so of the available energy of the vapour. Water, with its abnormally high latent heat, is therefore just as efficient a working fluid as any material of very low latent heat.

Indirectly, the boiling point is of importance in so far as

- 1.) A high boiling point permits an extension of the upper temperature range, without getting excessive pressures.
- 2.) A low boiling point permits the use of the fluid down to very low temperatures, without getting excessive volumes.

Since these two features are contradictory, a change of the working fluid ~~would be advantageous~~ during the cycle would be ^{promote} advantageous, starting with a material of high boiling point, as tin ~~chloride~~, then transferring the heat to a material of low boiling point, as ammonia.

In a turbine, high vapour density would be ~~advan~~ very advantageous, by reducing the velocity of the vapour jet, and so permitting the design of very few low velocity wheels, that is of high indicated efficiency.

The available energy of steam:

$$W = K p_0 \left\{ 1 - \left(\frac{p}{p_0} \right)^c \right\}$$

$$= 426000 p_0^{.06} \left\{ 1 - \left(\frac{p}{p_0} \right)^{.112} \right\} \text{ foot lb.}$$

gives for $p_0 = 200$ lbs admission pressure, and exhaust into a perfect vacuum, that is, complete condensation: $p = 0$,
the available energy:

$$W = 385000 \text{ ft lb}$$

hence

the spouting velocity:

$$v = \sqrt{2gW}$$

$$= 6120 \text{ ft sec.}$$

This probably is the molecular velocity of steam at 200 lbs pressure.

Dined on report May 20th 1906.

At the same pressure p_0 , the kinetic molecular energy of all vapours can be considered, for our purposes, as the same:

$$N m v^2 = \text{const}$$

where: N = number of molecules per unit weight volume
 m = molecular weight

v = molecular velocity, which should be expected as equal to the spouting velocity of the vapour jet at complete adiabatic expansion into the vacuum.

The number of molecules N per unit volume can be assumed as approximately proportional to the absolute temperature of the vapour at the pressure p_0 .

The ratio of the absolute temperature at pressure p_0 to the absolute temperature at ~~at~~ of the boiling point at atmospheric pressure can for our purpose be assumed as constant,

This then permits to estimate the spouting velocity of a vapour jet expanding from pressure $p_0 = 200$ lbs down to complete condensation, from the molecular weight and the boiling point at atmospheric pressure.

Denoting by index 0 the quantities referring to steam, it is:
Temperature of saturated steam at atmospheric pressure:

$$v_0 = 100^\circ\text{C} = 373^\circ\text{abs}$$

at 200 lbs pressure:

$$v_0' = 195^\circ\text{C} = 468^\circ\text{abs}$$

ratio:

$$q = \frac{v_0'}{v_0} = \frac{468}{373} = 1.255$$

If then:

v = temperature of boiling point of fluid,

It is:

$$v' = qv = 1.255 v = \text{boiling point of fluid at}$$

200 lbs pressure.

Therefore:

$$\frac{N}{N_0} = \frac{468}{1.255 v} = \text{ratio of mol number of molecules per}$$

unit volume, and:

$$\left(\frac{v}{v_0}\right)^2 = \frac{N_0 m_0}{N m} = \frac{1.255 v}{468} \frac{18}{m} = \frac{v}{20.7 m}$$

In table I are given the data on some compounds of high molecular weights:

Table I.

Working fluid:		Melting Point: °C.	Boiling point:			°C.
			atmospheric: °C.	at 200 lb. abs.:	at 200 lb. abs.:	
1)	Bromoform: CHBr_3	8	151	424	533	260
2)	Tin tetrabromide: SnBr_4	30	203	476	585	312
3)	Tribrom benzole 1-2-4: $\text{C}_6\text{H}_3\text{Br}_3$	44	275	548	688	415
4)	Tetrabrom benzole 1-2-3-5: $\text{C}_6\text{H}_2\text{Br}_4$	98	329	602	756	483
5)	Perchlor naphthaline: C_{10}Cl_8	203	403	676	848	545
6)	Mercury: Hg	-40	360	633	794	521
7)	Water: H_2O	0	100	373	468	195
8)	Ammonia: NH_3	-82	-34	239	300	27

	Molecular weight m:	$(\frac{v}{v_0})^2 = \frac{v^2}{20.7m}$	$\frac{v}{v_0}$	v^2 ft. the sec.
1)	CHBr_3	.0808	.284	1740
2)	SnBr_4	.0523	.229	1400
3)	$\text{C}_6\text{H}_3\text{Br}_3$.0840	.290	1770
4)	$\text{C}_6\text{H}_2\text{Br}_4$.0735	.271	1660
5)	C_{10}Cl_8	.0808	.284	1740
6)	Hg	.153	.391	2400
7)	H_2O	1.000	1.000	6120
8)	NH_3	.680	.825	5050

The values given in above table are approximate only, estimated as described, in the absence of more exact data.

Values of 300 to 500 seem to be the highest molecular weights, which can be expected of compounds capable to stand temperatures of 400° to 600° C without dissociation.

At these molecular weights, the vapor density is from 14 to 28 times that of steam, or from 10 to 17 times that of air. The spouting velocity is about one quarter that of steam, over the same pressure range.

That is, with a mechanically feasible wheel bucket velocity, of 500 to 600 ft. sec., the whole available energy of the expanded

vapour could be extracted in a single wheel.

A two stage turbine, with single wheel per stage, would bring the velocity down to the same or lower values than used in the Curtis turbine, and a ~~2~~ 2-wheel single stage structure would give bucket velocities lower than now used.

Theoretically, such a heavy vapour turbine appears therefore very desirable mechanically.

Obviously, the circulation of the working fluid must take place entirely in a closed space.

Hardly enough is known on the behaviour of compounds of high molecular weight, at high pressures and high temperatures, regarding their liability to dissociation, their action on metals etc., to consider the development of such turbines. Very desirable however would be a preliminary investigation of the literature on such compounds as may come into consideration, and that very soon, since the idea is rather near, and it would be preferable for us to lead rather than let others do the work and then have to pay for it.

It is interesting to note that Mercury compares rather unfavorably with the other compounds.

B. Low Temperature Turbines.

The use of such heavy vapours would extend the upper temperature limit of the thermodynamic cycle by about 200°C .

For an extension of the lower temperature limit, Ammonia does not appear particularly promising, its boiling point being so low that its use would involve high pressures. At higher temperatures, Ammonia is liable to dissociation.

Nevertheless, a more particular study of Ammonia as working fluid may be desirable and will be given in ~~it~~ some later report.

The use of a working fluid of high molecular weight and high boiling point at the upper limit of the cycle would almost necessarily require a different working fluid at the lower limit, since the lower temperature limit of the fluid of high boiling point should be considerably above its melting point.

The use, at the lower limit of the thermodynamic cycle, of a fluid as Ammonia, light hydrocarbons, or their non inflammable

chlorine derivatives, would however again lead to high spouting velocities, or due to their low molecular weights, and so give a more complicated system of wheels,

Very desirable would then be a working fluid of high molecular weight, at least 200 to 300, and low boiling point, about 50° to 60° C.

Such fluid would about have the constants:

Boiling point at atmospheric pressure:	55° C = 328° abs
" " " 200 lbs " " :	139° C = 412° "
Molecular weight:	200 to 300
$(\frac{v}{v_0})^2 = \frac{\rho}{20.7m} =$.0493 to .0528
$\frac{v}{v_0} =$.282 to .230
$v =$	1430 to 1410 ft. sec.

The existence of such compound appears doubtful, since high molecular weight is usually accompanied by high boiling point.

It appears to me therefore, that when endeavouring to reduce ~~simple~~ improve the turbine by the use of a heavy vapour, of low spouting velocity, the main difficulty appears at the lower limit of the thermodynamic cycle, and consists in finding a vapour of high density, which still has considerable pressure at condenser temperature.

A fluid for instance, with a boiling point at 200° to 300° C, could not be used below 100° to 200° C, due to its low pressure and so excessive volume at this temperature.

Using however a low density, high velocity fluid at the lower limit, would hardly improve matters sufficient over the present condition, to compensate for the complication of heat transfer from one to an other medium, and the use of a medium less harmless and more expensive than water.

On the present steam turbine, the proposition of extending the lower limit by the use of a fluid of lower boiling point, as chloroform, gasoline etc.)

does not appear very promising. ~~Since~~ With the reciprocating engine, where by considerations of volume the expansion has to be ended at a temperature considerably above condenser temperature, the SO_2 engine

has apparently not met with success. In the steam turbine, expansion is carried down practically to the condenser temperature without serious volume difficulties, and an auxiliary low temperature vapour stage therefore appears hardly called for.