Butlin, H. E. Dryden, H. C. Everitt, D. R. Fergusson (*Representative on the Examination Committee*), L. H. Finch (*Representative on the Council of the Institute*), C. J. Flamen, P. K. Le May, C. G. Matthews, A. Slator, A. H. Yeomans.

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OBITUARY.

We greatly regret to record the death on December 16th, 1925, at Copenhagen, of our distinguished honorary foreign member, Alfred Jörgensen, director of the well-known laboratory which bore his name. A notice of his life and work will appear in a subsequent issue.

MEETING OF THE NORTH OF ENGLAND SECTION HELD AT THE MIDLAND HOTEL, MANCHESTER, ON THURSDAY, 22ND OCTOBER, 1925.

Mr. Fred Hyde in the chair.

The following paper was read and discussed:—

SUPERHEATED STEAM IN PROCESS WORK.

By William A. Ward, A.M.I.Mech.E.

The extent and variety of industrial processes in which the application of heat by means of steam is fundamental justify a far more keen interest in the properties of the vehicle itself than that generally evident in the past. A great amount of thought and experiment has been devoted to the perfecting of plant and apparatus for the efficient exchange of heat, and actual processes have frequently been modified or rearranged with the same object in view. That this attention has been directed principally to the cold end of the system in the past is only natural in view of the significance of temperature difference in all problems of heat flow.

The more difficult conditions of the present day, however, especially the high cost of fuel, dictate an extension of the scope of heat balance sheets or diagrams, so that they embrace the whole field of heat production and utilisation in every direction simultaneously. Thus only can every avenue of loss be adequately dealt with and real progress made towards the ideal of a closed cycle. The place of superheated steam in this connection is definite and assured, although its neglect in process work as compared with power production is a melancholy fact for which engineers, chemists and plant managers must share the blame. The extent and ardour of recent controversy regarding its use for such purposes may be taken as a good omen, and consideration of the more important attributes, advantages and limitations may be useful.

Definitions.

For the sake of clarity, the following definitions are perhaps advisable at the outset:—

(*a*) *Wet steam* is that which has water suspended in it in the form of minute particles, or bubbles like those composing mist or fog. It is sometimes called super-saturated steam. (*b*) *Saturated steam*, or dry saturated steam, at a given temperature, is that which has maximum density for that temperature and its corresponding pressure. It contains the maximum quantity of heat which can be imparted to it at constant volume without increasing its pressure, or is "saturated" with heat. All the ordinary steam tables refer to steam in this state. (*c*) *Superheated steam*. If dry saturated steam be heated when not in contact with water, its temperature is raised and its density diminished, or its pressure increased. The steam is then said to be superheated. The superheated steam in general use is in open communication with the steam space of the boiler, so that its pressure is constant and its density diminished as compared with the steam leaving the boiler and entering the superheater. Such is the superheated steam referred to in the present paper except where definitely stated to the contrary. (*d*) *Total heat of steam* is the number of B.T.U., actually imparted to each pound of steam in generating it from water at 32° F., or the total heat in steam at any pressure, above that in water at 32° F. (*e*) *Latent heat* of steam, or heat of vaporisation, is the amount of heat absorbed in changing the state from the liquid to the "gaseous." It is usually expressed by engineers in B.T.U. per pound, and equals the total heat minus the heat in water at the temperature corresponding to the pressure, above that in water at 32° F. (*f*) *Available heat of steam* is that portion of the total which can be used in the performance of useful work.

Difficulties and Objections.

Dismissing mere prejudice, it must be admitted that difficulties have been experienced in the application of superheated steam, and objections to its adoption in certain cases appear quite justifiable on a superficial examination. Careful and patient investigation of the causes of failure, however, generally lead to exoneration of the practice of superheating as the primary cause, and it is virtually certain that it may be adopted to some extent, with advantage, in every case where steam is used, providing due care and restraint are exercised, and full realisation of its possibilities brought to each particular problem beforehand. Lack of this is entirely responsible for the spectacle of adjacent works in the same industry, operating under otherwise precisely similar conditions, with superheated steam in regular and constant use in one, and an almost fierce objection to it in the other, in consequence of early failure. This state of affairs is not confined to process work, but includes many cases of power production also.

The contradictory nature of the usual arguments and testimony will be seen from the following, which are actual utterances in every case :—

(1) "Impossible for us to use superheated steam as we have so much copper plant, and it would be destroyed by the extra heat."

(2) "Superheated steam has been used in this brewery for many years, and is the finest money saver we have ever found. We have never experienced any deleterious effect on either plant or product."

(3) "It is no use for heating purposes. We found a lower temperature in drying room than with saturated steam."

(4) "We dare not attempt to use superheated steam for fear of overheating, which would cause discoloration, even if it did not actually burn the material."

(5) "There can be no question about the heating value of superheated steam. It is proved to be greater than saturated steam by the fact that after the change was made, all the pipe coverings burned and had to be replaced with a better quality."

(6) "It is found to be necessary to increase heating surfaces about 2¼ times in order to get any advantage from the extra heat content."

(7) "The evaporator makers tell us it is no use, as we should actually do less work, same being in proportion to the amount of steam which can be condensed per minute and superheated steam being notoriously difficult to condense."

(8) "The greater heat would make the conversion too rapid in proportion to the rate of absorption, and there would be heavy deposits on the coils which would not only slow down the process, but damage the product, reduce yield, and possibly ruin the apparatus."

(9) "The drying oven capacity has been increased by more than 50 per cent. since superheated steam was adopted, yet we are saving coal, and have not experienced any burning."

(10) "The superheater went in without difficulty or delay, and although it is perhaps somewhat early to estimate results, we are already burning about 25 per cent. less coal."

(11) "The saving of 17 per cent. in weight of coal during the period of three months covered by the guarantee has now been increased to 20 per cent. through the operatives becoming more accustomed to the superheated steam. As you know, in our case the results are not complicated by economy in a power plant."

Many other cases of a similar nature could be cited by consulting engineers, or superheater makers, and whilst the results mentioned in the last three cases are admittedly better than the average, fortunately the earlier ones do not represent the general state of knowledge and thought on the subject.

They have been selected with a view to emphasising the need for closer co-operation and discussion, for which there must be ample material in the results observed during the seventy years since Hirn made his first experiments and demonstrated a saving of 22 per cent. due to superheating, which were confirmed in 1857 by Penn, who found an immediate saving of 20 per cent. due to fitting superheaters to the s.s. Valetta.

Steam as a Heat Vehicle.

Steam is used as a vehicle for conveying heat because it has the greatest heat capacity of all common substances which can be used as conveniently and with equal safety. The chief difficulty which has to be surmounted in its use, and one which applies equally whatever it is used for in this capacity, *i.e.*, power or process work, is its inherent tendency to condense and give up the bulk of its heat prematurely in doing so. The loss of heat which causes condensation cannot be entirely prevented even by the most perfect insulation extant. It can only be minimised, and therefore it must be counterbalanced by the supply of additional heat. Superheating the steam is the only reasonable and logical way of compensating for this inevitable loss, as by its use the whole of the steam is so changed in state that condensation is delayed until it has done its work as in the case of an engine, or until it arrives at the apparatus where condensation is actually to do work as in the case of process heating. Even if the heat actually lost in transit is greater than in the case of saturated steam, the reserve, in a well-designed installation, is sufficient to cover it. This touches the kernel of the question, and is in fact the true storm centre of recent controversy regarding superheated steam for process work.

Criticism of the principle, as distinct from particular application and effect, asserts that it is immaterial how the extra heat to compensate for transit losses is supplied; and, as there is difficulty in condensing superheated steam, it is better to rely on extra boiler capacity. Against this, advocates place (*a*) the relative cost of installation and operation of extra boilers, (*b*) the greater space occupied, (*c*) the higher efficiency of superheaters as observed in practice and demonstrable by theory.

It is manifestly impossible to deal exhaustively with all the principles and details involved in a comparatively short paper, but a general exploration may be usefully attempted.

Condensation.

Reference may be made to the investigation of condensation phenomena in fog and vapour by Aitkin and Kelvin, and "The Law of Condensation of Steam" by Callendar and Nicholson (*Proc. Inst. Civil Engineers,* 1897), who suggested the possibility of these phenomena applying in steam engine cylinders and the like. Also the experiments of Wilson (*Philosophical Transactions* (*A*), 1897) and Callendar, on "Vapours" ("*Ency. Brit.*"). These show that condensation takes place only when sufficient nuclei of suitable molecular dimensions are present, and that the "double" molecules present in steam under suitable temperature and pressure conditions can act as such centres of condensation, as do also dust, air, free hydrogen, free O_2, free CO_2.

Conditions can be profoundly modified and condensation promoted or retarded by—(*a*) electrical energy; (*b*) movement such as vibrations, flow of currents, or shock caused by sudden interruption or change of direction of same; (*c*) temperature change.

Electrical methods as applied to eliminating water, mist, fog, spray, &c., are exemplified by the Lodge and the Cotterill precipitation systems. Change of direction and shock by the various forms of steam driers or anti-priming devices. Temperature change by superheating. The first named is ruled out in the cases under consideration by its cost, and has only been mentioned for the sake of completeness. So far as the author is aware, it has only been developed commercially as a means of elimination of condensate, and not as a purely preventive measure. The second has only a limited application as a preventive measure by removal of comparatively large particles, which, in addition to promoting coalescence and so removing lighter particles which might otherwise pass forward and carry heat, would act as a conductor and increase the rate of heat loss in the manner explained later.

It is impossible to dry steam thoroughly by mechanical means or manipulation simply because it is impossible to prevent loss of heat from it. All steam as taken direct from the boiler is really wet steam. It cannot become dry saturated steam without the application of heat after further contact with the water from which it is being generated is prevented.

Superheating not only eliminates water, whether entrained or condensed, but also inhibits condensation while it lasts.

The latent heat being the energy required to change the state of the water from liquid to gaseous, it is obvious that this is entirely given up in condensing, by the time the steam has reverted to water. The magnitude of the possible loss by premature condensation is shown by the relation of the latent heat to the total, viz., 970 B.T.U. in 1,150 B.T.U. per lb.

for steam at atmospheric pressure, and 880 in 1,189 for steam at 100 lb. per sq. in. gauge pressure. It is an even greater proportion of the available heat. Thus condensed water in apparatus is practically no use, apart altogether from flow and distribution difficulties caused by it, and its action as a conductor. The heat content of the water in the boiler before the liberation of steam is a very different matter however, and the loss due to removal of entrained water, which is necessary for efficient distribution, is considerable, unless it is effected inside the boiler. The phenomenal success of the new and more efficient anti-priming devices recently put on the market is due to this. The way in which condensation proceeds under constant pressure may also usefully be borne in mind. Each decrement of temperature produces a corresponding quantity of condensation in saturated or wet steam, thus accounting for the presence of water in steam pipes and apparatus at the very highest pressures. When steam is expanding in an engine cylinder or in passing through a turbine, conditions are somewhat different. The latent heat of the portion which condenses goes to support the remainder at saturation temperature, but it is not possible to avoid condensation, however rapid the flow to a reduced pressure. This fact is frequently lost sight of in connection with process work, and the fallacy persists, that only an immaterial reduction of the pressure is suffered.

Superheating.

The first work done by a superheater is the evaporation of all suspended water, as no superheat can be imparted until this is done. Further energy supplied to the steam by heating beyond this point results in a rise of temperature, as no change of state, such as liquid to gaseous, is involved. According to existing theories this energy—which is manifest as a rise in temperature, and a diminution of density at constant pressure, or increase of pressure at constant volume—increases the mobility of the molecules, and also the repulsive power of the molecular forces. The way in which this takes place has been investigated in connection with the electrical theory of the structure of the atoms of which the molecules are composed, *i.e.*, electrons moving rapidly in orbits round a central nucleus. Our only concern with these higher and more controversial regions of physics is that the theories enable us to appreciate the changes which may be taking place when steam is superheated, the manner in which imparted energy is returned and utilised, its effect on centres of condensation, and the reason for the reduction in thermal conductivity of steam when superheated. Thus we know that no energy can be expended by steam without yield of heat, whether this is converted into mechanical work by some form of engine, simply transferred to some other body, or used in overcoming friction, inertia, gravity, &c., to produce a flow. All losses are, of course, expenditure of energy.

Condensation cannot take place until the repulsive power imparted to the molecular forces has been dissipated by yield of heat, so that the state of molecular attraction and relation consistent with the liquid state is again established. It is known that this does not always occur immediately the level of temperature normally consistent with condensation is reached. For some reason not yet completely explained, there is a time lag, and under certain conditions of flow, such as turbine nozzles, this can make an increase of 5 per cent. in the amount of steam discharged. While no proof is available, nor anything in the nature of an authoritative statement intended, it is conceivable that this effect may partly account for the unexpectedly good results sometimes found in process work. It also seems clear that no such results can be expected with steam initially in a wet and critical condition in such work.

The higher the superheat the greater the difficulty of condensing will be. This is made use of in certain process work, such for example, as distillation, and oil or spirit stripping by naked steam; deodorising of seed oils when highly superheated steam at a pressure below the atmosphere is bubbled through the oil for the purpose of removing the water and compounds held in the oil by it, and distilling others. Most process work, and particularly brewing, is likely to be hindered by high superheat, for which it may be regarded as useless.

Transfer of Heat.

All gases are worse conductors of heat than liquids, and although thermal conductivity definitely increases with their temperature, there is a wide variation. Nearly all liquids on the other hand have very approximately the same thermal conductivity, and it appears to increase with temperature so long as they remain in the liquid state. There is a very wide variation in the conductivity of solids, illustrated by the relation of the following metals, viz., silver 100, copper 73·6, aluminium 31·3, brass 23·6, iron 11·9, steel 11·6 and lead 8·5.

Expectance of a low thermal conductivity in superheated as compared with wet steam, which follows from this, is actually fulfilled, the presence of water apparently improving conductivity in wet steam. This explains why the loss of heat from pipes containing superheated steam is less than the increased temperature difference would indicate according to formula, for the same medium; and also why the loss is still further reduced by using low-pressure steam superheated, in preference to high-pressure saturated steam which would have a temperature nearly the same. It also illustrates the difficulty sometimes experienced in cooling and condensing superheated steam in apparatus for heating and boiling, especially with high boiling-point liquors and consequent small temperature difference, and in continuous counter-current apparatus where the hottest liquid and hottest steam come together.

Intensity and quantity of heat are confused in the common argument that burning of low-grade insulation material not originally intended for high-pressure work or superheating proves a greater discharge of heat to be possible or actually taking place. Flow of heat is prevented as far as possible by the insulation, and as there is a constant supply available inside the pipe the metal attains almost the same temperature as the steam. The temperature gradient through the metal is almost flat, but steep through the covering; whereas when heat is flowing as freely as it can be made to do by circulation, temperature difference, etc., the gradient through the metal may be quite steep. A similar mistake is often made when comparing the merits of different radiators in buildings, drying rooms, etc., by the rough-and-ready method of touching them or applying a thermometer to the surface. That which indicates the highest temperature is taken as the best, whereas it is in all probability the least efficient. A very fine metallic surface or a painted one will radiate less heat under similar conditions than a rough cast uncovered surface, yet actually be hotter to the touch or thermometer simply because heat is being retained. The same remarks apply to insulating material on pipes.

Apparatus may be specially designed for utilising fully and efficiently the heat content of highly superheated steam. For instance, stage working can be arranged in which the small amount of heat required for finishing a process at a high temperature, or some other process demanding a high temperature but not a large quantity of heat, can be worked by the steam first, within the range of its superheat so that moderately superheated steam passes on to the ordinary plant or the earlier stage.

Steam in a wet state passing through pipes, deposits a film of water on the surface, and the thickness of this film is determined by the rate of condensation, speed of flow and character of same, *i.e.*, laminated or turbulent, and rapidity with which the condensate is removed.

Although water is a better conductor of heat than the steam because of its density and molecular properties—there are more chains of molecules per square inch along which the wave motion of heat can pass and be communicated to the metal—and contact between it and the surface is better than in the case of a dry gas in a similar comparatively stagnant state, it will be obvious that an increase in thickness will affect the temperature gradient and the rate of heat flow. It must also be remembered that the steam is moving and fresh sets of its molecules are being brought into contact with each other and either the water film or the wall of the pipe, so that the basis on which relative conductivities have been previously compared is entirely changed.

Taking all these details into consideration, and assuming that the best conditions possible exist on the other side of the pipe wall for the maximum flow of heat, *i.e.*, cleanliness, efficient circulation and removal of bubbles or films of evolved gas, it appears to be certain the best results could be obtained in the complete absence of a film of water on the inside, provided the flow of steam were of such speed and turbulence as to ensure the necessary molecular contact to transfer the heat yielded. Such conditions cannot be actually attained of course, but clearly the thinnest film possible should be aimed at.

The character of heating surface is important because of its effect on flow, and retention of films and deposits. Rough or corroded surfaces cause inefficiency. The thickness of the film of water can be reduced by efficient drainage, and great attention to this is desirable. There must be an adequate reservoir for condensate, outside the working zone, maximum fall possible, and efficient traps.

The immediate increase in the rate of heating or evaporation observed when steam is "blown off" independently of the normal action of the trap is familiar to everybody. Analysis of what is taking place during this operation, in addition to being of general interest, will clearly indicate the manner in which moderate superheat in the steam may improve the rate of performing work and effect a saving of fuel, in spite of the difficulty of delayed condensation already referred to. The more important effects of this operation are increase in speed of steam across the heating surface, more rapid evacuation of condensate, reduction in thickness of water film, increase of temperature at the tail end resulting in a general rise in the average temperature difference between the steam and substance heated, cleansing of surface, and breaking up of strata so as to cause a change from laminated to turbulent flow. It is frequently found necessary to work continuously in this manner towards the end of a batch.

Clearly the advantages derived outweigh the loss of heat due to reduction in the quantity of steam actually condensed, which is usually the case, and the loss of heat contained in the condensed water. This is true as far as the rate of heat transfer is concerned, even if not so in every case with relation to fuel consumption.

With moderately superheated steam entering the vessel, similar conditions may be approached even with the circuit closed on the traps. The amount of superheat must not be sufficient to retard condensation unduly, and the exact amount will vary with the process and conditions established by the requirements of it. In most cases, however, the temperature difference will be great enough, in conjunction with the sudden expansion of steam beyond the control valve, to preclude the possibility of condensation being inhibited with any degree of superheat likely to be met in process work, viz., less than 100° F. at the control valve, as a maximum, and generally less than 50° F. The following conditions then obtain :—(*a*) The total quantity of water of condensation will be less for the same quantity of heat. (*b*) The danger of a cold tail end will be reduced. (*c*) The slight reduction in the rate of condensation will tend to increase the speed of steam near the tail end. (*d*) The speed at inlet will be greater because of the lower density of the steam and absence of water particles. (*e*) The temperature gradient in steam will be nearer to a straight line and the level higher, so that the average difference between steam and substance being heated will be greater. (*f*) Turbulent flow is more likely to be established. (*g*) All these are tending to reduce the thickness of the film of water.

Some reasons will be apparent from the foregoing for the success of superheating in certain cases and failure in others. Also that failure is not inherent in the practice of superheating steam for process work, but rather due to lack of appreciation of essentials leading to attempts to do the impossible, or secure results peculiar to some other use of steam. The placing of superheaters immediately before apparatus is obviously a mistake, unless some special process demands very high superheat. Even in that case the steam should be previously superheated for transmission purposes. It has been done all too frequently, and disappointment with results retarded legitimate development in other factories to the general loss. A case of attempting to distil naphthalene, which boils at 218° C. (424° F.), with steam at 100 lb. pressure superheated to 550° F., may be mentioned. It was only after failure realisation came, that as the temperature of the saturated steam was 338° F. the work could not be done even by making the naphthalene pot a thoroughfare for the whole of the steam produced in the works. Another instance occurred of trying to replace high-pressure steam with low-pressure superheated for vulcanising in connection with electrical work in a jacketed press and a closed steam circuit. These and others like them show a far too common failure to realise that a higher temperature cannot be obtained by superheating if the steam is condensed in order to get the maximum yield of heat, and that the superheat is only a small fraction of the total.

There are cases, of course, in which superheated steam is used in direct contact with material as the only feasible heat vehicle, on account of oxidation, combustion, fading of colours, &c., and penetration required, so that closed heating with high-pressure water is unsuitable apart from the very high pressure needed for the temperature. These are not of general interest however, and the cost of fuel for superheating is a necessary part of the cost of production. Again, in the case of gas producers, gas retorts, and high-temperature distillation, where naked steam highly superheated is used, there is usually waste heat available for producing it.

True Function of the Superheater.

In general it is better to look upon superheating simply as a device for minimising the effect of heat losses in transmission, and to rely on just sufficient to ensure delivery of dry or very slightly superheated steam throughout the whole of the distributive system, bearing in mind that the early stages of superheating yield the greatest share of the total possible saving in process work. The legitimate place for the superheater is therefore at the boiler, where it can be incorporated as a part of the generating plant and be made use of to increase the efficiency of the same by increasing the heating surface exposed to the hot gases from the furnaces. It would be difficult to exaggerate the importance of this in every installation, but particularly in connection with Lancashire type boilers as usually installed and operated for process work.

In some cases, due to overloading of heating surface, the efficiency is very low, and the additional surface presented by a superheater for absorption of heat makes an immediate increase of 6 per cent. to 7 per cent., in generation alone, before any direct saving in transmission or use is brought into account. Of course, the reduced evaporation, because of the superheat, is helping to effect this improvement. Five per cent. increase in the efficiency of generation is quite common, and it will be appreciated that this represents a saving of some 7·3 per cent. in coal, with an overall efficiency of 68 per cent. prior to the installation of the superheater, which is a fairly good figure.

The further saving during transmission and use of the steam has to be added to this. Assuming 150° F. initial superheat, which, with steam at 80 lb. gauge pressure, is 78·3 B.T.U. per lb., and 7 per cent. of the total heat in the steam from feed at 100° F. down to the same temperature of condensate, assuming same is returned to the hotwell at that figure by efficient heat exchangers in the plant: this further saving is equivalent to 10·3 per cent. in fuel, making 17·6 per cent. in all. This is on a heat basis alone, and does not include any increase in efficiency or improvement in process, as demonstrated in practice and explained in the earlier portion of the paper. It may be mentioned in passing that there is also a small increase in thermo-dynamic efficiency derived from the use of superheated steam in engines.

Economy realised.

From these figures it will be evident that, allowing for the fuel demand for producing the superheat beyond what is obtained in consequence of the improvement in efficiency of actual generation, the usual claim of 1 per cent. saving in fuel for every 10° F. of superheat at the boiler is not by any means exaggerated. In practice the saving comes out nearer to 1½ per cent. per 10° F. superheat in the case of simple non-condensing engines. Clearly the economy is not difficult to attain, nor confined to installations which are primarily inefficient.

If there is loss through priming due to overloading of the boiler, or characteristics of the feed water, a further saving results. To begin with, the reduced evaporation explained by the economy due to superheating will cure or, at the least, minimise it. Any entrained water still going forward, however, will be converted into steam and superheated to the same degree as the remainder by passing through the superheater, providing this is of adequate capacity, which is a *sine qua non*. The efficiency of this conversion will be higher than in any ordinary boiler, because of the efficient heating surface provided by the thin tubes and the large number of small streams.

This is another extremely important function of superheaters, and a cogent reason for their inclusion in every steam-raising plant. The specific heat of superheated steam ranges from ·48 for steam at atmospheric pressure superheated 50° F., to ·564 for 180 lb. gauge pressure superheated 150° F. For 80 lb. and 100° F., it is ·533. Allowing for increase from dry saturated steam, the average involved when imparting superheat is about ·5. Thus to superheat 80 lb. steam 100° F. requires 50 B.T.U. per pound, which is 4·2 per cent. of the total in the finally superheated steam. Therefore the improvement in overall efficiency of generation is sufficient to entirely wipe out the heat demand for the first 100° F. This is found in practice and agreed upon by engineers generally. Obviously, then, the manufacturer with a compact plant where 100° F. is enough may occasionally realise a greater saving in fuel than another who needs a higher superheat on account of long pipe-lines, which in general is the ideal case for superheating in process work.

Relation to Tail Heat Losses.

Wasting of the heat in condensed water is unfortunately far too common. Because this is of practically no use in a pan or vessel which has to boil, and operations are not continuous in a large specially designed multi-stage plant, but carried out in scattered units, purchased singly and erected at different times, it is allowed to drain into some pond and waste its heat in the ground and the surrounding air. The wasting of engine exhausts is even worse, as in that case latent heat is also dissipated. In all such cases the saving due to superheating looks even better, because it bears a greater ratio to the heat used.

If it were realised that, roughly speaking, 1 per cent. of coal is saved for every additional 8° F. in the feed water entering the boiler, and/or every 8 B.T.U. extra heat per pound abstracted from the steam in doing useful work means also a saving of 1 per cent. in coal, at an overall boiler efficiency of 72 per cent., this state of affairs would soon be altered. There are many ways in which this tail heat can be utilised—viz., preheating liquors, heating water for washing, warming, drying or conditioning of materials, heating buildings, preheating of feed water before economisers, etc. The quantity of steam used, nature of the process, size and arrangement of buildings, etc., will determine which is the best in each works.

Relation to other Fuel Economising Apparatus.

Superheating is unique among all devices for improving economy, because of the number of avenues of loss in which it operates and the high level of efficiency which may be attained in each. It is complementary to all, and no other can replace it or render it superfluous. The economiser, although an indispensable adjunct, is limited by the danger of corrosion attendant on a too cold feed at one end and the risk of evaporation in it by too great absorption of heat at the other. The superheater fills the gap without affecting the improvement secured by the economiser. Preheating of air for combustion can only be carried far enough to increase the fire temperature to the limit of safety of furnaces, flue crowns, boiler fronts, and tubes nearest the fire. Air has a specific heat only half that of steam, so exchange of heat with the hot gases is more difficult. The air heater therefore cannot utilise the heat unavailable to both boiler and economiser within the limits of feasible size, cost, safety, output, and general economy: so there is a definite place and function for both economiser and air heater, as well as superheater. Obviously, also, any other device for securing more efficient combustion and generation of heat, such as mechanical stokers, special furnace arrangement, forced or induced draught, smoke consumer, short circuit and leakage preventer, can act independently of the superheater, which is essentially a heat absorber. It may even assist some of these. For instance, both forced and induced draughts are liable to reduce efficiency in careless hands by excess air. Then, the increased speed of gases across the efficient surface of the superheater, due to increase in volume, improves the rate of heat transfer and tends to repair the defect. It has already been shown how it may assist feed-water preheaters and remedy priming troubles. Thus, while acting along with, and in cases improving the work of, other apparatus for securing higher efficiency, it also operates, in its own peculiar field, the transmission and use of the steam, in which none of these can render service.

In considering the claims of various economy devices the fact that superheating is effecting most of its attendant economy by reduction of the amount of steam required is often lost sight of. Scepticism is also felt regarding the possibility of obtaining the results claimed for various devices at the same time, because the total appears to exceed 100 per cent. Frequently this is simply confusion between percentage of total efficiency and of fuel consumption. To put it shortly, 50 per cent. overall efficiency means twice the fuel required at 100 per cent.; and a reduction of 33⅓ per cent. in fuel for 50 per cent. or 66⅔ per cent. of that for 100 per cent. leaves 33⅓ per cent. extra still being used, which corresponds to 75 per cent. overall efficiency.

It is difficult to exceed 46 per cent. overall efficiency with boiler only, if it is anything like fully loaded, whereas with the other appliances already mentioned 75 per cent. can be achieved and maintained easily.

Other Advantages.

Some other important advantages consequent on the use of superheated steam are :—

(1) Reduction in the number of boilers required for a given load, so economising space and saving on capital and running costs.

(2) Reduction in boiler feed water from 10 per cent. in good to 30 per cent. in bad cases where condensate is wasted.

(3) Prevention of black smoke, and general reduction, by relieving the load on the boilers and fluctuation of the same.
(4) Improvement in timing of processes, and general speeding up due to better distribution and the suppression of transit losses.
(5) Smoothing of departmental friction, generally found where there is faulty distribution of heat and waiting for steam.
(6) Saving of reagents, etc., and reduction of effluent when using direct or naked steam, because the same heat is available with less water. Constant strength of solutions more easily maintained. Speed of boiling greatly increased, due to better agitation produced by bubbles of steam which take longer to condense. The time is often reduced by 50 per cent.
(7) In stripping processes solvents are less liable to emulsification, so that their absorption efficiency is kept up, resulting in better yields, as well as economy of solvent. Loss of product less at separator because less water to be dealt with.

Effects on Apparatus.

The erstwhile dread of damage to plant and apparatus has been proved to be groundless as far as moderately superheated steam is concerned, and it is seldom found now. Some metals are naturally more suitable than others, and when possible in new plant these may be adopted with advantage, providing cost is not too high relatively. For instance, wrought steel steam pipes would be used in preference to cast iron or copper, although these latter materials are not so unsuitable as to require changing unless for high pressures or a high degree of superheat. It is chiefly a question of mechanical strength, homogeneity, and fatigue. The temperature range is greater when superheated steam is in use, and the stresses due to expansion and contraction consequently increased. Castings being notoriously unknown quantities, it is better to avoid them as a precautionary measure when any increase of this kind is being catered for, though it is not strictly necessary. The fact that locomotive engine cylinders and superheater headers are regularly made of cast iron, and work at pressures up to 200 lb. per sq. in. and a total temperature of 750° F. due to superheating, without failure or trouble, proves this conclusively.

There is no chemical action between the steam and metals below the temperature at which dissociation of the steam takes place and which is, of course, far beyond any figure attained in ordinary process work.

Again, the temperature at which any change in structure of metals likely to be used could take place is far higher than any we are concerned with, especially as it is virtually impossible for the metal to ever attain the temperature of the steam itself. Although copper, gunmetal and brass, especially in the form of castings, are less suitable than steel, iron and nickel alloys for superheated steam apparatus, their long and successful use in ordinary process work, coupled with consideration of the facts recited above, should indicate that their presence need not preclude its adoption.

Metallic jointing material is advisable, although the hard rolled laminated asbestos compounds are in regular and successful use, and quite good for ordinary sized joints. For large valves steel bodies and nickel alloy faces are the best, especially for pressures over 120 lb. per sq. in. Below 3 in. bore the ordinary high-grade gunmetal may remain, provided they have metal faces. Soft-faced valves are not suitable.

The remarks on condensation and the characteristics of superheated steam already made will have indicated the slight changes necessary in the calibration of plant and control of steam when superheating is adopted. It is generally a matter of a few hours' observation only, however. Frequently, as a result of early condensation and scarcity of steam at the end of a works remote from the boilers, there is disparity between the heating surface installed for doing the same work in the same kind of apparatus. If it is found that control of steam only is insufficient to allow for this under the changed conditions, and surfaces have to be altered slightly, the cost is certainly covered by the advantages. Such changes are very unusual in practice.

Engine and plant makers are naturally conservative sometimes with regard to the application to old apparatus not originally designed for it, and will protest as a protective measure or suggest expensive alterations. While these are always worthy of attention because of the possibility of getting still better results, it should be borne in mind that they are very seldom really necessary, but even when they are the improvement in results will justify the cost.

Description of Apparatus.

Enumeration and description of type and design of superheaters is beyond the purpose and scope of the present paper, but a brief general review of the main features, particularly those of special importance in process work, will be an advantage.

In general terms, the present-day practice is to make superheaters of steel throughout, whatever the pressure of steam may be. Whether for independent firing or combination with a boiler, they consist essentially of a number of small tubes about $1\frac{1}{2}$ in. diameter and $\frac{1}{8}$ in. thick, attached each end to steel header tubes or distributors which receive steam from the boiler, and deliver to the steam mains after superheating.

The small tubes are placed in the path of the hot gases, and steam flows through them in a number of parallel streams. In some designs the small tubes or heating elements are expanded direct into the header tubes, in others they are attached by some kind of bolted joint, and are thus easily detachable, which facilitates adjustment of heating surface and so regulation of the degree of superheat, cleaning and repair or renewal. The latter system has been criticised as an unnecessary refinement and complication, but the fact that practically every maker has adopted it in some form is probably sufficient comment on the point. In any case it is obviously superior engineering to provide for easy renewal, cleaning and adjustment in case of need, even if experience shows it to be very seldom necessary, provided the cost is not increased or difficulty of operation and supervision introduced thereby.

Regulation of superheat can be secured by means of obscuring dampers, or similar means for regulating the amount of hot gases passing over the heating surface. These are costly, however, and a further possible source of failure in time of need, so should be avoided except in extreme cases when regulation from hour to hour is necessary as a part of a process.

Mixing of saturated steam and superheated steam for the purpose of regulating is a practice very seldom resorted to now. It has many dangers, chief of which are ineffectual mixing, and danger of too much steam flowing through the by-pass pipe, so that there is not enough passing through the superheater to protect the tubes from overheating. The advent of the detachable element superheater has also rendered the by-pass arrangement superfluous in the majority of installations. That dampers are unnecessary generally as a purely protective device will be clearly indicated by the fact that elements usually last 12 years or more.

The best guarantee of safety of tubes is efficiency of the heating surface—viz., the rate at which the steam can be made to take up heat from the hot gases and carry it away, so that the metal never assumes a dangerous temperature. This can only be secured by ensuring that every tube takes its proportion of the steam and that the speed of same is adequate for a high transfer factor. A slight extra drop in pressure across the heater to ensure this is comparatively of no importance, especially in process work.

Clearly, therefore, a design in which the cross-sectional area of the tubes or thoroughfare and the length of travel can be more or less independently proportioned is the best. A recent patent in which a flat-drawn tube is used for this purpose may be mentioned. Double the heating surface with the same cross-sectional area is secured, and the tubes are safe at any steam pressure at present in general use.

Early failures, both in production and use of superheated steam, were chiefly due to lack of appreciation of these principles.

Another interesting type of heater is that in which, with a common inlet from the boiler, two supplies of steam of varying degree of superheat are available at different outlets, either for different process purposes or for engine and process respectively, or different types of engine. The regulation is automatic without moving parts, because the flow is in proportion to the demand for each degree and the heating surface provided in each section, designed to give the required superheat to such quantity. Should the demand for either degree fluctuate or cease, sufficient steam circulates automatically to protect the tubes in that section.

Exhaust steam is frequently used for process work, of course, when conditions permit. From the foregoing remarks on condensation and the critical condition due to yield of heat energy in the engine, it is obvious that superheating of such steam is advisable. When naked steam is used in process work the engines are occasionally worked without any lubrication in the engine cylinders, so that the exhaust may be quite free from any suspicion of oil or grease. In these installations superheated steam is not advisable in the primary steam, but the exhaust steam may be superheated in the downtake of the boiler in the ordinary way. In ordinary work, if the demand for superheat in the primary steam is small and the arrangements existing for firing and absorption of heat permit, the exhaust steam superheater can be placed behind the primary superheater in the downtake, and considerable economy of fuel realised, as against an independently fired superheater, which must of necessity operate at a low rate of efficiency. This is because of the danger of overheating the tubes with a comparatively small weight of hot gases entering at fire conditions, and necessarily leaving the heating surface at a temperature in excess of the heat required in the steam.

There have naturally been far more failures with independently fired superheaters than with those forming a part of a boiler installation. Many devices have been tried to obviate the dangers referred to above, and at the same time to realise a high efficiency. It cannot be done except by making other use of the waste heat from them in some other direction. The rate of heat transmission in the superheater must be strictly limited, and the high temperature of the gases from the fire reduced in some way before coming into contact with the tubes containing only the bad conductor, steam. Excess air at or just after the fire is usually the means adopted, but in high-temperature work there is danger of oxidation of the tubes. A recent patent covers the use of inert flue gases for diluting the hot gases. The most successful results have been gained, however, by installing a large heating surface and working on the radiant heat of the hot gases for the first pass, not permitting any contact heating until later, and so arranging the flow of steam that there is sufficient temperature difference and speed throughout to protect the tubes—*i.e.*, thoroughfare, length of tube, and sequence of flow through various heat zones.

Apart from these difficulties of the special case, superheaters are perfectly simple pieces of apparatus, devoid of moving parts or anything to get out of order. They have a long life, require little or no attention and will last for years without any cost whatever for repairs or maintenance. The fuel saved, alone, is usually sufficient in the first year to cover the entire cost of superheater and all alterations, apart from any of the other advantages mentioned.

Discussion.

The Chairman (Mr. Fred Hyde) said he desired to thank Mr. Ward for a most interesting paper. Certainly there was room in the average brewery for economy in steam-raising, but as brewers they were anxious not to gain economy at the expense of the product. It was, he thought, generally agreed that with fire-boiling there was a higher heating surface, and with the use of superheated steam where steam was used for boiling the worts, the conditions would approximate to those of fire-boiling. That, of course, was quite apart from the question of economy, but certainly in breweries where steam was used so much for heating, the checking of condensation was, on the face of it, an economy.

Mr. T. H. Wall asked whether the high temperature of the superheated steam would damage valves and the internal fittings of engine cylinders. He would also like to know whether the use of the appliance described by the author would interfere with the draught of the chimney. Was additional draught necessary?

Mr. Ward, in reply, said there was no reason why any trouble should be experienced with the engines providing due restraint and moderation were exercised in the application of superheated steam. In the past, superheated steam much too hot had been applied, owing to mistakes on the part of the designers of superheaters, and want of knowledge on the part of the engine makers. Nearly every engineer knew by now what degree of superheat he dare use for any particular engine. There were many cases of old colliery engines which were not designed for, or considered suitable for, the use of superheated steam, in which it had nevertheless been successfully applied because limited to 80 or 100°. Condensation losses would be suppressed at that figure, both in transit and in the cylinders, and, as had been shown in the paper he had read, the first 100° were obtained by the automatic increase in the efficiency of the boiler as a generator, so that a considerable saving in coal was effected without engine trouble. Superheated steam was dry, whereas in saturated steam the water bubbles or globules acted as a lubricant. Therefore the argument that saturated steam was better in that respect had some justification. At the same time, lubrication was not the function of steam, and he could quote cases where, owing to the use of superheaters, lubrication troubles caused by corrosion and emulsification of oil by water in cylinders had been overcome, and the saving of oil was considerable. As regards the superheater interfering with the draught of the chimney, he could say that there was nothing to fear in this direction. He did not know of a single case where the draught had been interfered with by the installation of a superheater. The area of the downtake, compared to the size of the flues in the boiler itself, was ample owing to the width across the back end of the boiler, to allow for accumulation of dust and dirt and still leave sufficient room for the passage of the gases between superheater tubes and boiler end. The whole of the gases did not pass between the tubes. Obviously the reduction in the quantity of fuel burnt to do the same work would reduce the volume of gases and so improve the draught conditions. Far from being a hindrance, it was often an improvement: chimney troubles were entirely obviated, and the dread of having to build a new chimney was removed.

The CHAIRMAN remarked that in a brewery where there were long lengths of steam pipe to carry the steam, the avoidance of condensation was a valuable point and should be kept in mind. He thought breweries presented a good field for the use of superheaters which perhaps no other business did to the same extent. The troubles experienced from water hammer and knocking in the pipes would be obviated to a certain extent by the use of the superheater.

Mr. WARD said that, with regard to Mr. Hyde's previous remark about economy at the expense of the product, he (Mr. Ward) was not an advocate of that at all. As he had tried to show in his paper, the keynote should be moderation and common sense, and obviously the amount of money which could be saved or made by attention to the product was far in excess of what one could hope to save by economies in fuel or even in complete boilers. He did not think that striving for economy in fuel would ever be likely to engross the attention of the brewer to such an extent that he would overlook this fact. Superheating would certainly tend to establish conditions with steam boiling, similar to those found with fire boiling, by which he meant that portion of the coil would be hotter than could possibly be the case with saturated steam. He had not had experience of stage working in actual brewing, but he could imagine it possible to arrange a coil in a copper in such a way that fairly highly superheated steam could be used in it first, and then pass on to the portion of the coil where condensation was taking place, so that inside the body of the wort there were very hot tubes interspersed with the others, giving heating surface for molecular contact similar to that in a direct-fired copper.

Mr. J. HAMER asked whether there would be more caramelisation in the brewing copper heated by superheated steam than there would be in the ordinary steam-heated copper.

Mr. WARD said he could not follow all the arguments he had heard on the subject of overheating and caramelisation, but he gathered there was a fear of too rapid caramelisation or caramelisation at the wrong time and at too rapid a rate for absorption, resulting in deposits on the coil and burning so that the quality would be affected or valuable material destroyed. After all, the temperature of the superheated steam used could never be as high as that met with in fire boiling, so that he (Mr. Ward) did not think that any such contingencies could arise. The circulation would, he imagined, prevent anything of the kind. He could assure those present that during thirty years he had never had a case where trouble of the kind had been experienced owing to the fitting of superheaters. Fire boiling could be adopted with safety, and he should imagine there was considerably less risk of the danger mentioned with superheated steam.

Mr. H. J. MARRIOTT asked if there was much deposit on the coil with superheated steam.

Mr. WARD said there should not be if the superheated steam was used in a wise manner and no excessive superheat employed. As previously stated, he did not know of any such case. The idea would generally be to get a small amount of superheat remaining in the steam when it reached its destination to do its work. Latent heat was transferred during condensation to the liquor or wort it was heating; therefore if the superheated steam was properly applied the temperature in the coil would not be very much higher than would be the case with saturated steam.

Mr. H. J. MARRIOTT said he should have thought that a small bore of steam would be used for entering the copper with superheat rather than a large bore.

Mr WARD said the whole point was that if superheated steam was to be used it should not be done piecemeal. Put the superheater where it could be of most use and where fuel could be saved, not only by drying the steam so as to cut out transmission losses, but also by improving the efficiency of the boiler. That was the reason he had tried to bring out the point as to the proper place for the superheater—namely, at the boiler. There it could do everything required; it could improve the efficiency of the generation and cover the whole distribution of the steam, saving condensation losses at all points. He would not say, if that could not be done at every boiler, they should not apply a superheater at all, but it ought to be the aim.

Mr. T. H. Wall inquired if there was any trouble in keeping the outside of the superheater tubes clean.

Mr. Ward replied that as a rule the outside remained perfectly clean. Where hard water was used there would be some entrained with the steam, evaporated and superheated, leaving a deposit, some of which remained behind in the superheater. There were cases he knew of where hard water was used and the tube had become blocked. That, of course, was with the older type of superheater, not designed to obviate it. If anything, deposit on the inside was worse than on the outside of the tubes, because the temperature of the superheater tubes was always considerably below that of the hot gases, and dust did not adhere easily. At any rate, the superheater of which he had spoken of was so designed that the outside of the tubes could be seen and a scraper or brush could be passed down to clean them if necessary whilst at work.

Mr. A. Clapham said he would like to ask a question in regard to forced draught. In one case the superheater pipe was placed behind the furnace door, and in the other case he had in mind the pipes were carried through the brickwork into the side flues and obtained their heat from the gases in the side flues. He inquired which of these arrangements, in Mr. Ward's opinion, would give the better result.

Mr. Ward said the point raised was a debatable one, as it depended entirely on the size of the superheater in the side flue where the temperature was very low, probably 700° F., and behind the fire where the temperature was probably 2,CC0° or 2,4C0° F. If working with a forced draught furnace like Meldrum's, with a much smaller superheater behind the fire door or baffle plate, there would be a higher temperature in the steam, but the probability was that some risk would be run of burning out of the superheater in that position. It was a fairly common practice to put the superheaters in the side flues for this purpose, and obviously there was a tendency to increase efficiency by placing the superheater in that position. Another point arose, however. There was a degree of superheat which practically would not carry air into the forced draught apparatus because there was too great a difference between the density of the steam and that of the air. He had found in practice that too great a superheat did not carry the necessary quantity of air into the fire, but carried very much more steam, so that combustion conditions were upset. It was better to work with the superheater in the side flue so as to get a more moderate superheat and a bigger proportion of air. The density of the steam passing in, being nearer to that of the air, seemed to carry more air in and improved matters all round, apart altogether from the question of superheater life.

A vote of thanks was accorded the author for his interesting paper.