Features of heat transfer to hydrocarbon fuel atbubble and film boiling

Abstract. The article presents the results of a study of heat transfer from a heater to aRT grade hydrocarbon fuel.A number of features of heat transfer during boiling of hydrocarbon fuelinbubbleandfilmmodeswerediscovered.Thepresenceofself-oscillationsoccurringduring heat transfer is noted.

Comment [EO1]: Defined RT at first

Comment [EO2]: The numbers or values of the heat transfer features should be integrated to ascertain the bubble and film modes

Comment [EO3]: The self–oscillations should also be mentioned to know actual heat transfer oscillating

Comment [EO4]:

1. Introduction

Intensificationofheattransferduringfuelboilingisoneoftheactualproblemsofaircraftengine building, while heat transfer depends on the boiling mode.In the bubble boiling mode, the heat fluxistentimesgreaterthaninthefilmoneatthesametemperatureofwallsurface.Previously, afundamentallynewmethodwasproposedforintensifyingheattransferduringboilingofliquids under heated to the saturation temperature [1, 7]. This method allows to increase the stability of the “heater-liquid” system by using the optimal heat load [1–6,7, 8,& 9].

Comment [EO5]: This work on [7] need to be cited

Comment [EO6]: These works on Numerical Simulation of Powering Turbofan Propulsion Aircraft with Electricity and impingement of [7, 8,& 9] need to cited to improve aircraft simulation understanding and impingement heat transfer processes

Theissuesofheattransferduringfuelsboilingareofgreatinterestinthedesignofaircraft. The scientific and technical literature addresses issues related to the formation of deposits in fuel systems of power plants [7] and to the fuels bubble boiling [8,9],however,despite the importanceoftheproblem,systematicresearchinthefieldofheattransferduringfuelsboilingunderhigh heat fluxes was not detected.

Inthepresentwork,theprocessofheattransferduringfuelboilingundersuperintensebubble boiling (SBB), as well as in other modes under conditions of high-density heat flow, was studied [1–6]. The aim of the research was an experimental study of the heat transfer characteristics of hydrocarbon aviation fuel in a wide range of temperatures of the heated surfaces.

2. ObjectsofStudy

TheobjectofthestudywastheRTgradehydrocarbonfuel(GOST10227-86),usedinmodern aviation GTE. This fuel is a mixture of hydrocarbons with a distillation temperature in the range from 135°C to 280°C.

Comment [EO7]: See comment above if not yet defined

3. Experimentaltechnique

The electrothermographic method was chosen as the main research method.The heater,inadditiontoitsintendedpurpose,isusedasaresistancethermometer.Theheaterwasmadeof

Comment [EO8]: Could you justify why this method was chose in place of others. Please mention other methods and justify the one you chose platinum wire with a strong dependence of the electrical resistance on temperature.The wire was heated using a constant electric current. By fixing its current-voltage characteristic during the experiment, one can obtain information on the magnitude of the heat flux and surface temperature.Thermal power was supplied to the heater in the mode of stabilized average-integral resistance, whereby the mode of constant temperature of the heater was simulated [1]. A stabilizer of average integral resistance based on a proportional-integral-differential (PID) regulator was used to implement this mode [1].

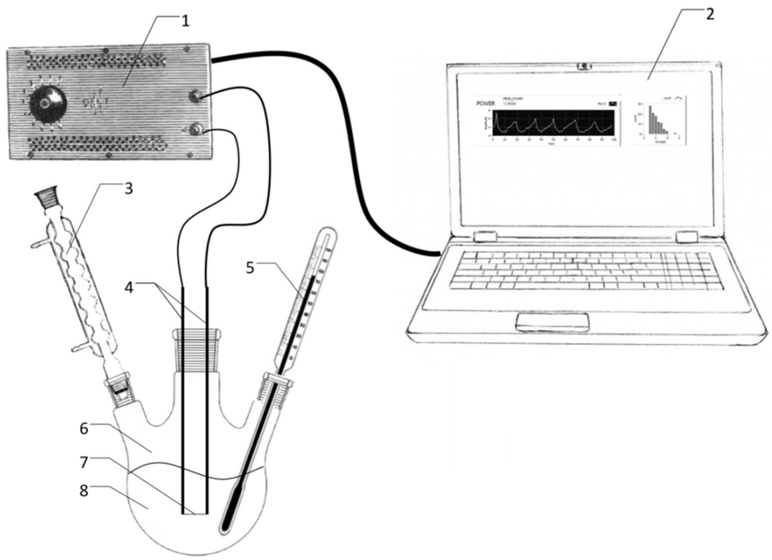

Figure 1. The experimental setup:1 – temperature regulator [1], 2 – laptop, 3 – air cooler, 4 – copper electrodes, 5 – thermometer, 6 – three-neck flask, 7 – platinum filament, 8 – test fluid.

The experimental setup is shown in figure 1.Electrodes, representing insulated copper wireswithadiameterof2mm,withasolderedplatinumwireof1.4cmlengthand0.1mmdiameter (heater)wereintroducedintoathree-necks50mlroundbottomflaskthroughthecentralneck andimmersedintheliquidunderstudy.Theheaterwasinstalledatadistanceof0.5–1cmfrom the bottom of the flask.Through the side necks, a reflux condenser and a mercury thermometer were installed.All connections were sealed.The volume of the test liquid was 15 ml.The flaskwasplacedinathermostatwithadjustabletemperature.Atwo-channel“ADVANTEST 6452A”multimeteranda“KEITHLEY2000”precisionmultimeterwereusedtomeasurethe heattransferparameterstothefuel. Alaptopandthe”IEEE-488.2GPIB”interfacewereused to collect data. Additionally, optical isolation modules “Q-SHUTTLE-KEL KIS-81GP000B-P” wereused.Theprogramwritteninthegraphicalprogrammingsystemdisplaysallmeasured data in a multi-window mode with the waveform vs time analysis and the histograms of specific powerandtemperaturecalculation.Theboilingcurveisdisplayedinaseparatewindow.

4. Discussionofresults

Since the experiments were carried out in the mode R = const, the maximum resistance of the systemtothermalperturbationsisachieved.Thisallowsyoutomostaccuratelydeterminethe

Comment [EO9]: Justify why R = Constant of make a reference value of the first critical heat flux [1].The transition boiling branch in this case is a mode of mixed boiling, which means the simultaneous coexistence of bubble and film boiling.Figure 2 shows a summary graph of boiling curves obtained for three temperatures of the RT grade hydrocarbon fuel.

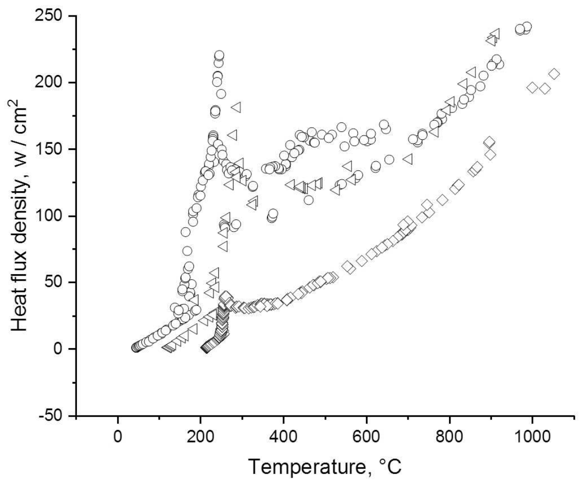

Figure2. BoilingcurvesofRTgradehydrocarbonfuel.Fueltemperature: ∘ –18˚C,*a*–98˚C, ▪–185˚C.

Ascanbeseenfromthefigurewhenboilingonthewirewithunderheatingoccurs(ata fuel temperatures of 18˚C and 98˚C), the maximum heat flux is significantly higher than when boiling on the wire of a saturated liquid occurs (at a fuel temperature of 185˚C). Moreover, during boiling with underheating, it is possible to achieve the regime of superintense bubble boiling (SBB) [1].

Comment [EO10]: You need to eeds to be

Figure 3 shows in more detail the bubble boiling branch for a liquid temperature of 18˚C. Itisnoteworthythatthreedifferentmodescanbemarkedinthebubbleboilingbranch.The CD branch corresponds to the mode when the entire heater is covered with a layer of fixed bubbles.This mode is critically replaced by the EF mode in which the bubbles are set in motion,movingalongthewire.Andfinally,theFGmode,itcorrespondstothesuperintense bubbleboiling(SBB)mode[1].Thisbehaviorofthebubbleboilingbranchisobservedforthe first time; in all the individual liquids studied earlier [1–6], this branch depended linearly on the heatertemperature,andtheobservedregimesgraduallytransformedintoeachother.Asthe underheating decreases, this feature gradually degenerates and the curve takes on a traditional appearance.

Another characteristic feature in the behavior of the system was identified in the region of mixed boiling.This area is located behind the critical heat flow (point G in figure 3) and continues to film boiling mode.

Figure 4 shows in more detail the mixed fuel boiling branch of the RTgrade hydrocarbon fuel atatemperatureof95˚C,obtainedinaseparateseriesofexperiments.Whenthethermalpower control mode is selected, the mixed boiling region is a temperature domain that first increases its temperature (section AB), and then, when the equilibrium heat flow is reached, it begins to spreadalongtheheater(sectionBC).TheCDsectionisanareaoffilmboilingregime,which

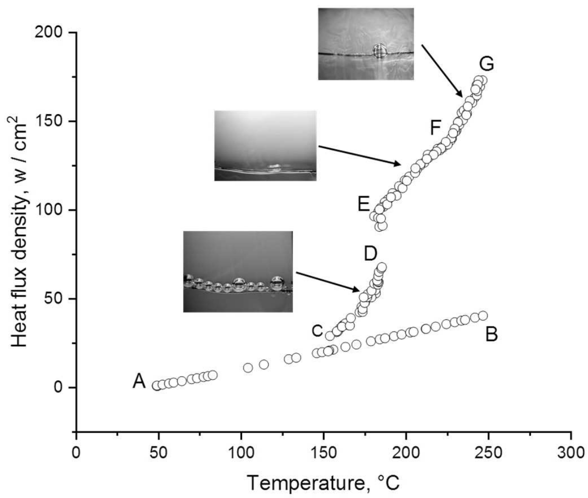

Figure3. Bubble boiling branch of RT grade hydrocarbon fuel for 18˚C. AB is a branch of free-convection heat transfer, CDEF is a branch of bubble boiling, FG is a branch of superintensebubble boiling (SBB).

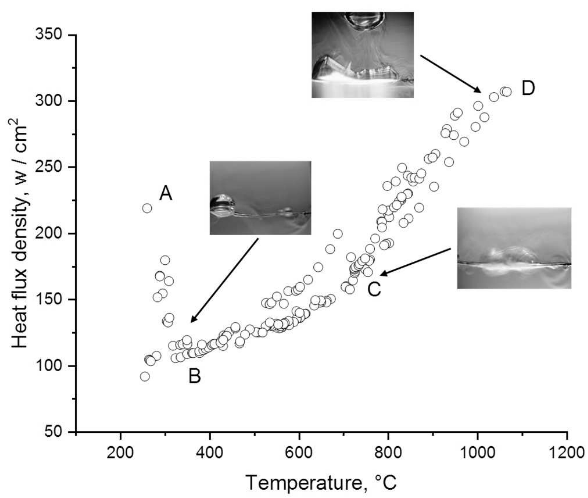

Figure4. ViewofthemixedfuelboilingregionofRTgradehydrocarbonfuelfor95˚C.

for the considered object of study, as well as the BC area, is poorly reproduced.In all previously studied systems, the areas of mixed and transitional boiling are reproduced with great accuracy, and their behavior is described by mathematical equations [1–6].At a fuel temperature of 95˚C, theseregionsdemonstratealargescatterofexperimentalpointsandacriticalphenomenon–the

BCD bend – which is not reproducible with high accuracy in subsequent experiments.It should be noted that each experimental point on the graph represents the averaging of one hundred measurements performed in automatic mode.

Measurement of the dynamic characteristics of the system allowed us to identify the reasons for the low reproducibility of measurement results in areas of mixed boiling.It turned out thatin these areas self-oscillations of power are observed, leading to non-reproducible parameters and a critical phenomenon – the bending of BCD. The type of self-oscillations observed is shown in the screenshot of the registration program of experimental parameters in figure 5. The right sideshowsthenormaldistributionoftheresultsofpowerdensitymeasurement.Asfollowsfrom the figure, the frequency of the self-oscillation process increases with increasing temperature of the heater.Note that in practice, self-oscillations are a periodic change in the linear dimensions ofthetemperaturedomainsattheheatersurface.Suchbehaviorwasnotobservedinanyofthe previously studied systems [1–6].

Comment [EO11]: What are the uncertainty in your measurement.
See reference [9] for updates and hints

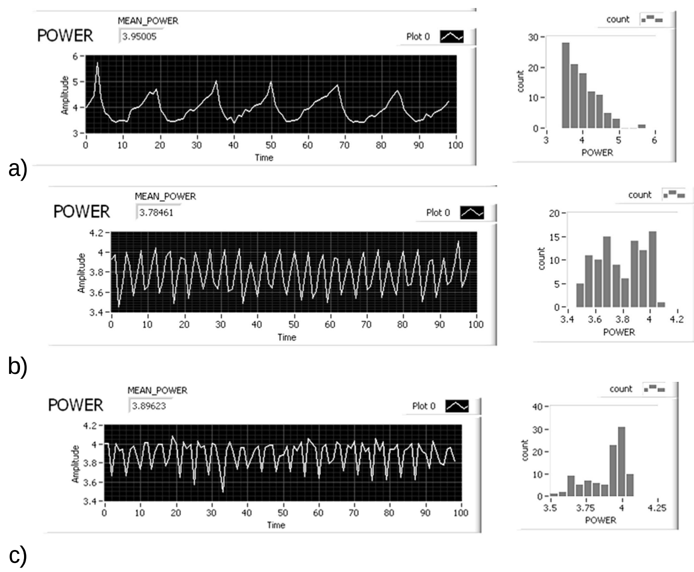

Figure 5. Self-oscillating heat transfer mode in the mixed boiling region. The average integral temperatureoftheheater:a–300°C,b–420°C,c–487°C.

5. Conclusion

Thus, we carried out a systematic study of heat transfer from a heated heater to a RT grade hydrocarbon fuel.It was found that in the bubble boiling regime the magnitude of the maximumheatfluxdependssignificantlyonthetemperatureoftheliquid.Theuncharacteristicbehavior of a bubble boiling branch and the existence of a mixed boiling region of a self-oscillating heat-transfermodearerevealed.Weassumethatthedescribedfeaturesoftheboilingcurve are determined by the fact that the hydrocarbon fuel under investigation is a mixture of hydrocarbons with different boiling points and that during the heating of the heat-transfer surface some of the low-boiling hydrocarbons evaporate, which makes it difficult to establish a steady-state heat transfer.

References

[1] ZhukovSA,Afanas'evaSYandEchmaevSB2003*Int.J. HeatMassTransfer***46**3411–3427
[2] ZhukovSA,BarelkoVVandMerzhanovAG1980*Int. J. Heat MassTransfer***24**47–55
[3] RagvanshiAK,SainiJSandPrakashR1992*Int.J.HeatMassTransfer***35**343–350
[4] DhugaDSandWinbertonRHS1985*Int.J.HeatMassTransfer***28**1860–1880
[5] RattoY A1990*Int.J.HeatMassTransfer***33**611–620
[6] OhtakeHandKoizumiY2004*Int.J.HeatMassTransfer***47**1965–1977
[7] **Onah T.O**.,Nwankwo A.M**.,** andAka C.C. 2023. Analytical Comparison of Top and Bottom Jet Impingement Controlled Cooling Configuration Using CFD. *European Journal of Mechanical Engineering Research.* 10(2). 32-45
[8] Onah T.O., Christian C. Aka and Bertrand N. Nwankwojike. 2023. Numerical Simulation of Powering Turbofan Propulsion Aircraft with Electricity, *Engineering and Technology Journal*. 41(1). 132-141
[9] Onah, T.O., Ekwueme, B. N., Odukwe, A.O., Nwankwojike B. N., Orga, A.C., Egwuagu, M. O., Chukwujindu, S.,Diyoke, C., Nwankwo A.M., Asogwa,T.O.,Aka,C.C., Enebe K.C. and Asadu,C. O. (2022). Improved design and comparative evaluation of controlled water jet impingement cooling system for hot-rolled steel plates. *International Journal of Thermo fluids.* 15(3): 1-15
[10] Myakochin A S and YanovskyLS 2001 *Formation of Deposits in Fuel Systems of Power Plants and Methods for Their Suppression*(Moscow:Izd-vo MAI)
[11] YagovVV,YanovskyLS,GalimovFMandTimoshenkoAV1994*HighTemperature***32**810–814
[12] KutateladzeSS1979*FundametalsofHeatTransferTheory*(Moscow:Atomizdat)